

TECH. NOTE
R.P.D.24

TECH. NOTE
R.P.D.24

UNCLASSIFIED

SECRET

ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

DISTRIBUTION STATEMENT A

Approved for Public Release
Distribution Unlimited

TECHNICAL NOTE No: R.P.D.24

Inv 83

INV 90

PICATINNY ARSENAL

SCIENTIFIC AND TECHNICAL INFORMATION BRANCH

THE CARTRIDGE-OPERATED PROPELLANT FEED SYSTEM FOR THE R.T.V.I ROCKET MOTOR

by

W.H.BOND, A.M.I.Mech.E. and

A.C.MERRINGTON, Ph.D., F.Inst.P.

ROCKET PROPULSION DEPARTMENT, WESTCOTT

INVENTORY 1972

This document contains technical information of foreign origin. The information, so long as it remains classified, is not to be used or disclosed in any manner likely to prejudice the rights of the originator to obtain patent protection in respect thereof. If it is desired to use or disclose the information in any manner likely so to prejudice the rights of the originator, then the Office of Naval Intelligence will be notified of such intended use or disclosure, and such use or disclosure shall not be effected until approval has been obtained by the Office of Naval Intelligence from the country of origin. The use of this information for evaluation purposes within the National Military Establishment is not considered to be prejudicial to any military interests that may exist.

EXCLUDED FROM AUTOMATIC REGRADING;
DOD DIR 5200.10 DOES NOT APPLY

REVIEW ON May 80

MINISTRY OF SUPPLY

THIS DOCUMENT IS THE PROPERTY OF H.M. GOVERNMENT AND
ATTENTION IS CALLED TO THE PENALTIES ATTACHING TO
ANY INFRINGEMENT OF THE OFFICIAL SECRETS ACT, 1911-1939.

It is intended for the use of the recipient only, and for communication to such officers under him as may require to be acquainted with its contents in the course of their duties. The officers exercising this power of communication are responsible that such information is imparted with due caution and reserve. Any person other than the authorised holder, upon obtaining possession of this document, by finding or otherwise, should forward it, together with his name and address, in a closed envelope to:-

THE SECRETARY, MINISTRY OF SUPPLY, MILLBANK, LONDON, S.W.1.

Letter postage need not be prepaid, other postage will be refunded. All persons are hereby warned that the unauthorised retention or destruction of this document is an offence against the Official Secrets Act

Best Available Copy

SECRET

UNCLASSIFIED

20071109042

Royal Aircraft TN RPD 24

S

5 118709

21050-57-001

664203848 580 611 / 9

~~SECRET~~
UNCLASSIFIED

U D C No. 621.455-44

10 L Technical Note No. RPD. 24

6 L May, 1950

G.B.

2 L ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

4 L The Cartridge-Operated Propellant Feed System
for the R.T.V.1 Rocket Motor

by

W.H. Bond, A.M.I Mech.E.

5 and

A.C. Merrington, Ph.D., F.Inst.P.

SUMMARY

This note describes the development of the cartridge-operated propellant feed system for the R.T.V.1 rocket motor which provides a thrust of 900 lb and a total impulse of approximately 19,000 lb sec; the propellant flow rates are 3.46 lb/sec of methanol diluted with water and 2.18 lb/sec of liquid oxygen. Both fuel and oxidant tanks are pressurized simultaneously to 425 lb/sq in with the gas produced from the controlled burning of a single solid propellant cartridge. The pressurizing gas is isolated from the fuel and oxidant by pistons which traverse the tanks so discharging the propellants. The total cartridge weight is 9 lb and the powder alone weighs just under $4\frac{1}{2}$ lb.

In the initial stages of the work, leakage of oxygen past the piston resulted in secondary combustion of the pressurising gas and led to the use of an oxygen-rich powder based on ammonium nitrate. This was satisfactory although succeeding batches did not give the same result and sampling in the actual rocket motor proved necessary.

- | | |
|-----------------------|---------------|
| 1. Rockets | I Bond, W. H. |
| 2. Test vehicles | II Title |
| 3. Propellant control | III RTV 1 |
| 4. Methanol | |
| 5. LOX | |

UNCLASSIFIED

~~SECRET~~

Best Available Copy

LIST OF CONTENTS

	<u>Page</u>
1 Introduction	4
2 General description of propellant feed system	4
3 Operation of system	5
3.1 Filling propellant tanks	5
3.2 Functioning of system	6
4 Development of components	7
4.1 Description of experimental rig	7
4.2 Oxidant piston	8
4.3 Fuel piston	9
4.4 Oxidant vent valve	10
4.5 Insulation of oxidant tank	11
5 Development of gas generating cartridge	11
5.1 Functioning tests using cartridge	12
5.2 Final design of cartridge	12
5.3 Difficulties of batch reproduction	13
5.4 Operating conditions for cartridge	14
6 Conclusions	15
References	15
Advance Distribution	16

LIST OF TABLES

	<u>Table</u>
Summary of tests for producing final design of cartridge	I
Comparison between predicted and actual performance of cartridge	II

LIST OF APPENDICES

	<u>App.</u>
Fitting the oxidant piston	I
Liquid oxygen vent valve	II
Assembly of the oxidant tank lagging	III

LIST OF ILLUSTRATIONS

	<u>Fig.</u>
Lay-out of propellant feed system	1
Fuel tank filling operation	2
Oxidant tank filling operation	3
Variation in weight of liquid oxygen in oxidant tank during and after filling	4
Orifice fitting	5
Mobile test stand	6
Original design of oxidant piston	7
Experimental oxidant piston seals	8
Final design of oxidant piston	9
Original oxidant tank vent valve	10
Final design of oxidant tank vent valve	11
Oxidant tank lagging	12
Typical breech pressure and temperature record during functioning tests	13
Typical gas pressure records from breech during charge development tests	14
Assembly of cartridge	15
Temperature variation at burning surfaces of cartridge and in air space behind oxidant piston during and after oxidant filling	16
Typical gas temperature records from breech and behind oxidant piston using final charge	17
Measurement of oxidant tank bore	18
Oxidant piston belling tool	19
Oxidant piston extractor	20

1 Introduction

The thrust requirements of the R.T.V.1 missiles fall into two groups: (a) a minimum of 800 lb, and (b) a minimum of 1,000 lb. This note describes the development of the propellant feed system of a motor to meet the first of these. This motor provides a thrust of 900 lb and a total impulse of approximately 19,000 lb sec. The propellant flow rates are 3.46 lb/sec of a 60% methyl alcohol/40% water mixture and 2.18 lb/sec of liquid oxygen.

Pressure feed, in preference to a turbo-pump system, is dictated by the size of the missile and the pressurizing gas is isolated from the fuel and oxidant by pistons which traverse the tanks and so discharge the propellants. This arrangement ensures that a continuous flow of fuel and oxidant is maintained regardless of the attitude or acceleration of the missile; a pre-determined centre of gravity shift is also obtained.

Of the methods available for providing the necessary pressure, the simple compressed gas arrangement was rejected as being far too heavy and bulky and a system in which gas is produced from the controlled burning of a solid propellant cartridge was chosen. Although this technique for the ejection of liquids had been well established in this country during the war, no information existed on the behaviour of liquid oxygen under such conditions. For this reason test experiments on a simple apparatus were carried out by A.R.E.⁽¹⁾, White Lea, in which liquid oxygen alone was expelled at a flow rate of about 3 lb/sec using both cordite and plastic charges. These tests were successful although there was some evidence of leakage past the piston during filling, even though the vessel had a machined internal bore.

As a result of these tests the complete R.T.V.1 feed system was designed by A.D.E. in collaboration with A.R.E. and the manufacture of specimen components followed. Trials carried out at A.R.E., White Lea, with this equipment proved that the design of tanks and pistons, particularly the oxidant tank and piston, needed considerable modification. At this stage the work was transferred to Westcott where development continued and finally a successful design was reached. For the purposes of these tests the combustion chamber of the motor was replaced by orifices calibrated to give the appropriate flow rates.

Static and flight tests on the complete motor comprising expulsion system, combustion chamber, valves and timing mechanism, are described separately⁽²⁾. Other aspects of the work, including the development of the combustion chamber⁽³⁾, assembly and test of the motor⁽⁴⁾ and some of the problems encountered in its manufacture⁽⁵⁾, are also reported separately.

The work described in this note was largely completed in 1948, but owing to the over-riding necessity of providing a rocket test vehicle, reporting has been delayed. Experiments required to determine the correct cartridge design for satisfying requirement (b) at a thrust of 1,075 lb are expected to be completed shortly. Some tests at high ambient temperature then remain to be done on the feed system to check its behaviour under conditions likely to occur at L.R.W.E., Australia.

2 General description of propellant feed system

The lay-out of the propellant feed system is shown in Fig.1. The solid propellant cartridge is housed in, and attached to, the heavy forging at the open or forward end of the fuel tank. This forging on

which the wings are mounted in the actual missile forms the breech or chamber in which the cartridge burns, the ends of the chamber being closed by the fuel piston and the base of the oxidant tank. Gas from the burning charge comes directly into contact with the fuel piston and is conveyed to the oxidant piston by six pipes equally disposed around the periphery of the breech. Considerable difficulty was experienced in sealing the oxidant piston and in order to make use of the differential contraction resulting from dissimilar metals this piston was made of mild steel. The entrance of each gas delivery pipe into the forward end of the oxidant tank is displaced by 180° from its exit in the breech and thus provides a half coil which allows for expansion and contraction without placing strains on the end joints. The oxidant delivery pipe is taken from the base of the oxidant tank along the outside of the fuel tank after which it passes through the fairing connecting the fuel tank and the combustion chamber strong ring and hence to the combustion chamber injectors. The fuel delivery pipe is taken straight from the base of the fuel tank through the same fairing. A bellows made of very thin aluminium alloy is fitted between the fuel pipe and its respective attachment to the combustion chamber injector to allow for expansion and contraction of the pipe; the shape of the oxidant pipe line is such that the larger movement expected from this cause can easily be accommodated without the use of bellows. The oxidant pipe is lagged with asbestos tape over the complete length from the oxidant tank to the combustion chamber. Both fuel and oxidant pistons are fitted at the forward ends of their respective tanks and move rearwards during their stroke.

The solid propellant cartridge is ignited by passing low tension electric current through two igniters, one at each end of the cartridge. The end of the cartridge adjacent to the oxidant tank contains a boost charge which is ignited simultaneously with the main charge by the same igniter. The boost charge consists of $2\frac{1}{2}$ oz of cylindrical pellets $\frac{3}{16}$ " diameter with a length/diameter ratio of 1. These pellets possess a large surface area/weight ratio and produce a relatively large quantity of gas in a very short time of burning and thus create the correct pressure and temperature conditions for the main charge to sustain.

A vent valve is fitted into the oxidant tank immediately in front of the leading edge of the oxidant piston to permit the escape of gas produced by the evaporation of liquid oxygen. This valve is closed by the initial movement of the oxidant piston during its stroke.

A small set-screw is screwed into the fuel tank wall just in front of the leading edge of the fuel piston. This screw is removed during the filling operation in order to vent the tank.

The oxidant tank is smaller in diameter than the fuel tank and is lagged with a uniform thickness of magnesium carbonate powder to provide some measure of insulation for the liquid oxygen. The powder is held in place around the curved surface of the tank by a P.V.C. sleeve which in turn is supported by an aluminium alloy fairing of the same diameter as the fuel tank. Both ends of the oxidant tank are also lagged with magnesium carbonate powder.

3 Operation of system

3.1 Filling propellant tanks

The filling operations are carried out with the longitudinal axis of the tanks inclined at 30° to the horizontal. This attitude of the tanks was selected in order to simulate final launching conditions.

Owing to the rapid evaporation rate it is essential to fill with oxidant when the vehicle is in the final launching position.

The fuel tank is filled under pressure from a special trolley as shown in Fig.2. The vent screw is removed from the fuel tank and the supply pipe from the filling trolley is connected to a non-return valve situated at the lower end of the fuel delivery pipe. The spherical tank on the filling trolley is pressurized to 10 lb per sq in by compressed nitrogen, and a solenoid-operated valve controls the supply of fuel to the rocket tank. Filling is continued until fuel overflows from the vent screw aperture. The vent screw is then replaced, the supply pipe disconnected, and a blanking cap screwed over the non-return valve as an added safeguard against leakage.

Definite time limits are set for filling the oxidant tank to ensure as far as possible consistent initial temperature conditions for the cartridge. It is important to note that the oxidant tank must be lagged with the recommended amount of magnesium carbonate or it may be impossible to fill the tank within the required time. The oxidant tank is filled under pressure from an expense tank as shown in Fig.3. The supply pipe from the expense tank is connected to a non-return valve at the lower end of the oxidant delivery pipe. The reason for using the expense tank, which is filled from the bulk storage tank, is that the latter is only capable of withstanding a pressure of about 10 lb/sq in. The pressure in the expense tank is maintained at approximately 35 lb/sq in but this pressure varies slightly with the length and bore of pipe connecting the expense tank to the rocket tank. The criterion which determines the pressure to apply to the expense tank is that the rocket tank must be filled within the period 5 - 8 minutes. Filling is complete when liquid oxygen spurts in a steady stream from the vent valve aperture. At this point the supply pipe from the expense tank is disconnected and a blanking cap fitted to the non-return valve.

At the commencement of the oxidant filling operation of the R.T.V.1 most of the liquid oxygen flowing through the delivery pipe changes into gaseous oxygen before it reaches the oxidant tank. This part liquid, part gaseous flow continues in varying proportions until the evaporation process has lowered the temperature of the delivery pipe sufficiently, when a preponderance of liquid oxygen is delivered to the oxidant tank. In the oxidant tank the same process of cooling by evaporation of the liquid oxygen continues until the tank is at a sufficiently low temperature to retain the liquid oxygen in its liquid form. The curve given in Fig.4 shows the weight of liquid oxygen in the oxidant tank plotted against time during the filling operation and after the filling operation has been completed.

3.2 Functioning of system

It is extremely important that the cartridge is fired at a pre-determined time after the oxidant tank is filled, for the following reasons:-

(i) Owing to the evaporation of liquid oxygen the initial free volume for which the boost charge is designed increases rapidly with time.

(ii) The close proximity of liquid oxygen reduces the temperature of the cartridge, the breech and, in fact, a large part of the system, progressively with time; the performance of the cartridge is affected by the initial temperature distribution throughout the system and the burning rate of the composition itself is also a function of temperature.

(iii) The differential contraction effect of the oxidant tank on the liquid oxygen piston increases with time.

The time between completion of oxidant filling and firing the cartridge has been set at 4 minutes \pm 5 seconds.

After the cartridge is fired, gas is evolved and builds up pressure in both the fuel and oxidant tanks. When this pressure reaches 75 - 100 lb/sq in a shearing disc in the oxidant orifice fitting (Fig.5) is ruptured and oxidant commences to discharge at approximately 0.5 seconds after firing the cartridge. As the pressure builds up to 300 lb/sq in the shearing disc in the fuel orifice fitting is ruptured and fuel is discharged at approximately 1 second after firing the cartridge. The time delays between firing the cartridge and rupturing the two shearing discs are purposely arranged to simulate the starting conditions in the combustion chamber. Expulsion of the fuel and oxidant continues for 20.5 seconds when all the fuel is expelled. The expulsion cartridge is designed to maintain full pressure for 22 seconds to ensure that the performance of the motor is maintained until all the fuel has been burnt.

4 Development of components

The components of the propellant feed system were first made to function correctly using approximately half the weight of solid propellant in the cartridge. After the components had proved reliable in use the final weight of solid propellant was determined.

The results of the trials carried out by A.R.D., White Lea, proved that the original designs of tanks and pistons were unsatisfactory, particularly the oxidant tank and piston. The main difference between the preliminary tests on the simplified apparatus⁽¹⁾ and those on R.T.V.1 was that in the former case the vessel used had a machined internal bore held to close limits whereas the fabricated R.T.V.1 tanks could only be held to wide limits. Consequently, although a satisfactory piston seal against liquid oxygen was obtained in the preliminary tests, when R.T.V.1 tanks were used the same type of piston proved useless.

Further experimental work was held up, therefore, until satisfactory piston seals had been achieved in the fuel and oxidant tanks. The liquid oxygen vent valve had also proved unsatisfactory and this was, therefore, redesigned. The oxidant tank lagging was next developed and finally the correct weights of the main charge and boost charge were determined and a suitable cartridge was designed.

4.1 Description of experimental rig

The first propellant expulsion tests were carried out with a tank arrangement and test stand rather similar to that shown in Fig.3, but not mobile. The oxidant and fuel pipes were connected to orifice fittings through junction pieces from which filling connections were taken. The orifice fittings, shown in Fig.5, contained a shear disc assembly, a pressure tapping positioned after the shear disc, and finally an orifice through which the fuel or oxidant was expelled to atmosphere. A safety disc was fitted to the forward end of the oxidant tank and was designed to rupture at 480 lb/sq in in order to safeguard the tanks from damage should higher pressures tend to develop. The tanks had been stressed originally to the 0.2% proof stress at an internal pressure of 450 lb/sq in. The safety disc fitting was attached to the breech at first, but after an unforeseen difficulty, which is discussed later, was moved to the fuel discharge line and thereafter to a position communicating with the space behind the oxidant piston.

The R.T.V.1 fuel tank is designed for the closing end to be welded to the tube after the fuel piston has been fitted. It is, therefore, impossible to remove the fuel piston once the tank has been made. When a fuel tank has been used for an expulsion test the piston is slightly distorted through 'bottoming' on the tank, and after the piston has been traversed back to its starting position it will not seal satisfactorily. To prevent the consequent wastage of fuel tanks it was decided to use a modified fuel tank for expulsion tests. This type of tank had a light alloy flange welded to the tube in place of the closing end, and was sealed by a closing plate bolted to the flange as shown in Fig.1. With this type of tank the fuel piston could be removed after firing and a new piston fitted, thereby enabling the tank to be used indefinitely provided it was not unduly stressed.

From safety considerations the expulsion tests were conducted in the open, and the cartridge was fired remotely from a concrete control room below ground level. To facilitate work on the tank rig prior to firing, and to enable the work to be done under shelter, a mobile test stand was constructed as shown in Fig.6. This stand was made quickly adjustable for height and inclination. Work can be carried out on the tank rig at a convenient height with the stand horizontal, and when the stand has been towed into position ready for filling the tanks, it is quickly elevated and locked into position.

4.2 Oxidant piston

Sealing the piston in the oxidant tank against liquid oxygen proved to be a formidable task. The manufacturing method adopted for the tanks⁽⁵⁾ created most of the difficulty. The tanks are made by rolling 10 S.W.G. light alloy sheet (MG.5) into a cylinder and butt welding the edges down the length of the cylinder. A mandrel is then drawn through the tubes in an effort to obtain a truly circular bore. After pressure testing, the tubes are welded to the tank ends which are machined from forgings. This method of manufacture does not permit close limits to be set for the internal diameter, ovality, and taper of the tank bore. With the limits which were eventually set the mean internal diameter of the bore was held to within 8.000 in and 8.030 in, subject to a maximum ovality of 0.030 in.

The original design of the oxidant piston is shown in Fig.7(A). This piston was a light alloy pressing using a T-shaped Gaco ring as a seal, held in place by a light alloy ring secured to the piston by bolts; the slotted skirt allows the gas to be admitted from the six pipes.

After it had become evident that large quantities of liquid oxygen were leaking past the piston, the domed cover plate was removed from the oxidant tank and the piston held in place at the end of the tank by transverse metal straps. By removing the cover plate the position of the leaks could be seen. Although the piston provided an effective seal against water, liquid oxygen leaked badly through the bolt-holes and past the sealing ring. The leak through the bolt-holes was cured by fitting brass washers over the bolts, but the leak round the Gaco ring persisted. An O-section ring (Fig.7(B)) was then fitted in place of the T-section ring, but the change effected no improvement in sealing against liquid oxygen. At the temperature of liquid oxygen the ring material became extremely hard and brittle, showing no inclination to obturate as it did at normal temperatures.

When it had been established that the original sealing ring material was unsuitable for use with liquid oxygen, various organizations and firms were approached for materials which would remain flexible at very

low temperatures. Various proprietary makes of packing were tried but found to be unsatisfactory and the most promising material discovered was water-dressed, de-greased, oak tanned leather. This material was supplied in the form of cup-shaped washers and flat washers both slightly larger than the piston diameter. It was anticipated that the cup-shaped washers, shown in Fig.8(A), would obturate under the filling pressure and provide a satisfactory seal. This result, however, was not obtained and some alternative methods of pressing the washers against the tank wall were tried as shown in Fig.8(B), (C) and (D). All these methods failed to make the washers provide a static seal against liquid oxygen.

The flat leather washers were originally obtained to back the cup-shaped washers, as shown in Fig.8(E) and it was noticeable that the liquid oxygen leak was much reduced when a flat washer was fitted behind one of the cup-washers. It was decided to try two of the flat washers alone as a seal and in order to get the maximum effect from the clamping ring this was provided with a flange, as shown in Fig.8(F). In addition studs were fitted to the clamping ring and sweated in position with soft solder to obviate leaks through the bolt-holes in the ring. A lead washer supported by a flat steel washer was placed on each stud on the piston side. This arrangement produced an almost perfect static seal and provided the basis on which a new piston was designed.

As a result of the experiments with the flat leather washers it was considered possible to achieve a perfect static seal against liquid oxygen if the washers were compressed between two flat surfaces with sharp corners at the edges. The piston was accordingly designed so that the piston skirt made a sharp corner with the washer recess, and the flange on the clamping ring was replaced by a parallel portion of the piston crown, as shown in Fig.9. The leather washers were pressed over the crown and compressed between the clamping ring and the piston by studs screwed and sweated into the clamping ring. Lead washers and flat steel washers fitted under the nuts provided a seal for the studs. The piston is fitted into the oxidant tank with the clamping ring nuts loose and the nuts are tightened when the piston is in its correct initial position. The nuts are tightened until the lead washers commence to extrude from under the flat steel washers; this effectively limits the degree of compression which can be applied to the leather washers.

The piston was designed to be made in light alloy (MG.5) but owing to the long delivery time of forgings, it was made in mild steel initially. When the first light alloy pistons were tried trouble was experienced due to the piston skirt picking up during its stroke, and causing the piston to seize. It was decided, therefore, to revert to machined mild steel forgings which had proved very satisfactory. Owing to the manufacturing tolerances permitted on the oxidant tank and piston diameters some trouble was caused by the piston tending to misalign itself with reference to the axis of the tank during its stroke. This trouble was cured by cutting a 10° chamfer on the leading edge of the clamping ring as shown in Fig.9 and belling out the edge of the piston skirt to suit each particular tank. The method of fitting the oxidant piston is described in Appendix I.

4.3 Fuel piston

The fuel tank is manufactured in the same way as the oxidant tank and the same dimensional tolerances apply. The difficulties experienced with the fuel piston, however, proved far less onerous than those with the oxidant piston owing to the greater range of compatible materials available.

The fuel piston was originally designed as a pressing in 16 S.W.G. light alloy with a T-shaped Gaco ring for a seal in a similar manner to the liquid oxygen piston, shown in Fig.7(A). This seal proved unreliable in use as the top edges of the T-section tended to curl up during the piston stroke. The length/diameter ratio of the piston was so very small that any tendency for one part of the piston to stick immediately threw the piston out of line with the tank bore and so caused it to jam. In addition, the T-shaped ring did not provide an effective static seal.

The final design of the fuel piston is similar to that shown in Fig.7(B) for the liquid oxygen piston, except that the slots are omitted. Little could be done to improve the length/diameter ratio as any increase in the length of the piston would have decreased the amount of fuel carried. The tendency for the piston to get out of line, however, was overcome by increasing the thickness from 16 S.W.G. to 13 S.W.G; this improved its rigidity. The piston seal was also changed to an O-section Gaco ring; this gave a satisfactory static seal and was not prone to stick during the piston stroke. To ensure that the piston seated squarely in its initial position three long hexagon nuts were substituted for three of the ordinary nuts used to attach the sealing ring channel to the piston crown. These long nuts are seated on the rear face of the strong ring at the front of the fuel tank. A pressure test was instituted to ensure that the piston made a satisfactory static seal before a piston and tank assembly was passed for use in an experiment. The test consisted of supporting the tank vertically with the open end facing downwards, filling the tank with three or four gallons of fuel and admitting nitrogen at a pressure of 20 lb/sq in to the tank above the fuel for 30 minutes. During this test there must be no trace of fuel leaking past the piston.

4.4 Oxidant vent valve

The oxidant vent valve was provided to vent the gaseous oxygen produced in the oxidant tank during the evaporation process, and to seal the vent when the tanks were pressurized. The original design is shown in Fig.10. The valve was housed in the thick flange of the oxidant tank end forging, and a passage welded to the side of the tank connected a hole through the tank wall in front of the piston with the valve housing. With the valve in its venting position the hole in the tank was connected to atmosphere. When the expulsion cartridge was fired gas pressure on the underside of the valve lifted it onto a seating in the valve housing. This design was very unsatisfactory because gaseous oxygen leaked through the valve into the space behind the piston thereby shutting the valve and so preventing the liquid oxygen in the tank from venting. An attempt was made to seal the space behind the oxidant piston by spring loading the valve onto a seat in the bottom of the valve housing. This arrangement did not prove very satisfactory because the expulsion gas had to close the valve against this spring pressure. This design of valve was eventually discarded, however, because of the difficulty experienced in welding the passage to the tank wall.

The final design of oxidant vent valve is shown in Fig.11. The valve is held in the venting position against spring pressure by a shear pin made from 24 S.W.G. copper wire. At the beginning of its stroke the oxidant piston lifts the plunger which breaks the shear wire in the valve. The valve is assisted onto its seating by the movement of the plunger and the spring held against the flange on the plunger. The valve boss is secured to the tank wall by twelve 6 B.A. set-screws and the seal between the contoured base of the boss and the tank wall is effected by a rubberized fabric washer. The set-screws are cleaned off flush with the bore of the tank. Each valve is lapped to its seat and tested prior to assembly in the oxidant tank; this test is described in Appendix II.

4.5 Insulation of oxidant tank

The first unsuccessful attempts to fill the oxidant tank with liquid oxygen proved the necessity for efficient lagging of both the filling pipe and the oxidant tank. The problem of lagging the oxidant tank was complicated by the six gas delivery pipes which are fitted close to the outside of the tank. The first lagging method used, which enabled the tank to be filled with liquid oxygen, was to surround the tank with a 4 inch thick layer of slag wool held in place by asbestos tape. The delivery pipe was also lagged with two thicknesses of asbestos tape. Attempts were made to find more suitable insulating materials and asbestos fibre and powdered magnesium carbonate appeared to be the best available.

After a few trials asbestos fibre was discarded in favour of magnesium carbonate. A cylindrical sheet metal wrapper with two longitudinal flanges bolted together was made to encircle the tank so as to leave a one inch annulus between tank and wrapper. The space between the wrapper and the tank at the forward end was stuffed with asbestos fibre for approximately two inches and the magnesium carbonate was poured into the remaining annular space except for the extreme rear end which was sealed as before with asbestos fibre. This arrangement was used for the trials concerned with the initial development of the expulsion cartridge. In arriving at the final cartridge design it was necessary to develop a method of lagging which would be suitable for flight trials. The lagging method finally adopted, shown in Fig.12, makes use of a P.V.C. sleeve to retain the magnesium carbonate in contact with the tank; this sleeve is supported by a light alloy fairing. The method of assembly is described in detail in Appendix III.

5 Development of gas generating cartridge

As already pointed out in para.4, the early tests on R.T.V.1 tanks showed that the original type of piston seal was quite ineffective against liquid oxygen. Since the gas produced by the cordite and plastic propellant expulsion charges then in use contained an excess of fuel, secondary combustion occurred with oxygen leaking past the piston and the light alloy tanks were melted near the forward end. A perfect seal against liquid oxygen, at least during the filling period and preferably during the piston stroke also, was, therefore, required.

Two lines of action were followed to overcome this difficulty. The first was to design a satisfactory piston seal against liquid oxygen in the R.T.V.1 tank; the second was to find a solid propellant producing surplus oxygen which would not give rise to secondary burning in the presence of oxygen. The outcome of the search for a satisfactory piston seal has already been described in para.4.2 and was successful in that a satisfactory static seal was achieved. A solid propellant made from a pressed powder composition, consisting mainly of ammonium nitrate and containing surplus oxygen, was found and it was decided to use this composition in conjunction with the new type of piston seal.

The composition is referred to by the manufacturers as O.C. 7/0.5 and has the following percentage composition:

Ammonium nitrate	78.5
Potassium nitrate	9.0
Ammonium dichromate	5.6
Ammonium oxalate, anhydrous	6.9

A small quantity of china clay, 0.5 - 0.9% is also added. The rate of burning of the composition is, of course, dependent on the burning pressure, but can also be controlled independently by varying the percentage of china clay in the mixture; the greater the amount of china clay present, the slower is the rate of burning.

5.1 Functioning tests using cartridge

The first experiments with the propellant feed system carried out at R.P.D. using a solid propellant cartridge were mainly functioning tests to ensure that the components of the system were satisfactory. Most of these were done with petrol as the fuel since the decision to change to alcohol in order to ensure reliable operation of the combustion chamber had not then been made. A solid propellant charge weighing 3 lb 2 oz (to I.C.I. Specification O.C. 7/O.5) calculated by the method referred to elsewhere⁽⁶⁾ was used with no boost charge. Pressure records were taken from the breech, the gas space behind the oxidant piston, and the oxidant and fuel orifice fittings. A typical pressure-time record is shown in Fig. 13. Thermocouples made up from chromel-alumel wires held in sparking plug bodies were used in conjunction with millivoltmeters to obtain temperature records from the gas space in both fuel and oxidant tanks; a typical record is included in Fig. 13.

The first test using the new design of oxidant piston resulted in an explosion. It is possible that petrol leaked into the breech during the fuel filling operation and caused an explosion when the charge was ignited. The explosion misaligned the fuel piston and opened the welded diaphragm in the breech end of the oxidant tank and thus allowed fuel and oxidant to mix with the burning charge in the breech. The difficulty was eliminated by limiting the fuel filling pressure to 10 lb/sq in, testing the piston seal before use, as described in para. 4.3, and using a forged end for the oxidant tank in place of the thinner welded diaphragm.

A safety disc was originally fitted in the breech to prevent damage to the tanks should the gas pressure rise above 400 lb/sq in, but the disc ruptured below this pressure on one occasion and the resulting rapid drop in pressure sucked back fuel and liquid oxygen into the breech and caused an explosion; this occurred when the oxygen piston seal was still undergoing development. Subsequently the safety disc was moved to the fuel discharge line. In this position the safety disc often ruptured below the designed pressure owing, probably, to a pulsating effect set up when the fuel bursting disc ruptured. It was finally connected to the space behind the oxidant piston where it functioned satisfactorily.

5.2 Final design of cartridge

After the components of the propellant feed system had proved reliable in the functioning tests, experiments were undertaken to produce the final design of main charge and boost charge to give the required pressure-time characteristic.

To vary the area of the burning surface of a pressed-powder type of propellant it is necessary to vary the internal diameter of the charge container. As this requires quantities of tubing of various diameters, which were not available at the time, it was decided in consultation with the manufacturers of the propellant charge to have a constant burning surface and to vary the rate of burning of the composition in order to achieve the required performance. It was further decided to use the steel tubes produced for the 5 inch A.T.O. solid propellant rockets for the charge containers. These tubes were readily available in the

quantities required; they provided the largest burning surface that could conveniently be housed in the breech, and were capable of withstanding the charge pressing pressure.

From the records of the charge performance that had been obtained during the functioning tests the manufacturers estimated the required increase in the rate of burning and prepared more sample charges for further tests in the R.T.V.1 expulsion rig. These charges were tested by the manufacturers by burning the charge at one end only in a small cylindrical steel vessel and allowing the gas to exhaust to atmosphere through a calibrated orifice. It was hoped to establish a correlation between the pressure obtained by this method and the pressure obtained in the R.T.V.1 propellant expulsion experiments. Although records were obtained from several different charges and a satisfactory composition of main charge and boost charge was finally obtained, there appeared to be no direct correlation between the two methods of testing the charges.

A summary of the main tests carried out to produce a satisfactory main charge and boost charge is given in Table I. The pressure records obtained from the breech during some of these tests are shown together in Fig.14; these clearly show the effect of increasing the size of the boost. The correct charge, indicated by the last test in Table I, is 4 lb 3 oz plus a 2 $\frac{1}{2}$ oz boost. As the composition and weight of main charge and boost charge was now established the final design of charge container was prepared and is shown in Fig.15.

5.3 Difficulties of batch reproduction

Having obtained a satisfactory experimental batch of cartridges a further small batch was ordered pending the completion of sufficient charge containers to complete the original order for 250 cartridges. It was very disconcerting, therefore, to find that the new cartridges did not repeat the performance of the previous batch, and, in fact, a further five batches of cartridges were tested in R.T.V.1 before an acceptable performance was obtained. A comparison between the pressure specified by the manufacturers and the actual pressures recorded in the R.T.V.1 propellant expulsion tests is given in Table II. Charges from any given batch, however, gave reproducible results in R.T.V.1 to within about ± 15 lb/sq.in.

With an apparatus similar to that employed by the manufacturers an attempt was made to repeat their tests in an effort to find the cause of the discrepancy. Owing to lack of time available insufficient work was done to draw any definite conclusions, but the general inference was that this type of test was not sufficiently sensitive for the purpose. The design of a test rig based on the R.T.V.1 expulsion gear, but of a much simpler construction, was also considered but it was doubtful whether the temperature distribution throughout the system would approach that of R.T.V.1 sufficiently closely for the results to be of any real value. Since, however, the number of batches to be tested was small and especially as the manufacturer had adopted a new manufacturing technique, which gave a much greater measure of control on performance, it was decided to continue the testing in the R.T.V.1 expulsion rig.

In the new method two stocks of powder are prepared, one with a lower rate of burning than required, and the other with a higher rate of burning. Sample cartridges are made using definite proportions of the two stocks of powder blended together and these are tested in the R.T.V.1 tank rig and pressure-time records obtained. If this pressure record is unacceptable fresh sample cartridges are prepared, and the proportions of the two stocks of powder are varied as necessary to increase or decrease the rate of burning in order to produce the required pressure.

5.4 Operating conditions for cartridge

The functioning tests described in para.5.1 showed that the close proximity of liquid oxygen affected the initial temperature of the breech and hence also that of the cartridge. Consequently, it became obvious that if the cartridge was to give reproducible results the length of time that liquid oxygen was in contact with the apparatus, prior to firing, would have to be carefully controlled. This entailed keeping the oxidant filling time to within set limits and fixing a definite interval between the cessation of oxidant filling and firing the cartridge.

Several tests were undertaken to find out the variation with time of the temperature of the cartridge, and that of the space behind the oxidant piston, during and after the oxidant filling operation. A chromel-alumel thermocouple was held in contact with each exposed surface of the main charge and readings of temperature were recorded from the commencement of oxidant filling until 20 minutes after the tank had been filled; these results are shown in Fig.16. Chromel-alumel thermocouples were also screwed into the oxidant tank domed closing plate projecting about one inch into the gas space behind the oxidant piston. Temperature readings were taken from these thermocouples during the oxidant filling operation and for 10 minutes after the tank was full; a typical record is included in Fig.16. From a consideration of these results and as a result of experience gained in the filling operation the oxidant filling time was controlled between the limits 5 - 8 minutes. This incidentally ensured that the whole system and, in particular, the vent valve had been assembled correctly; any additional leak greatly reduced the filling time.

It was also decided to set a limit of 4 minutes \pm 5 seconds between the cessation of oxidant filling and firing of the charge. The mean filling time and the corresponding firing time are indicated in Fig.16. Gas temperatures in the breech and behind the oxidant piston recorded under these conditions and with the correct charge are indicated in Fig.17. The metal wall temperature in the vicinity of the breech is, of course, much lower than that indicated by the figure and reaches a maximum of only 230°C.

It is important to realize that the present design of charge will give the desired performance if the above times are held to the limits specified. If, however, the cartridge is fired much before the time given, then the pressures will be high with consequent risk of tank failure. If on the other hand the time is allowed to exceed 4 minutes by any great amount, experience indicates that the results are likely to be erratic owing, most probably, to partial seizure of the piston in the oxidant tank. It should be pointed out that this disadvantage of a definite firing time dictated by the filling operation would not occur with oxidants such as H.T.P. or nitric acid.

A gradual drop in performance of the cartridge over a period of six months was traced to the absorption of moisture on the charge surface. It was known that the composition was hygroscopic and charges were therefore stored, a number at a time, in tins having lids sealed with luting. This evidently was not adequate and each charge is now canned by the manufacturer as it is made and a small quantity of silica gel included in the tin.

Some information was required on the temperatures likely to be encountered in the battery compartment of the projectile situated between

the base of the telemetry head in the nose and the insulated plate next to the forward end of the liquid oxygen tank. Measurements made with a dummy head in place showed a fall in temperature of less than 1°C over the entire filling and firing period

6 Conclusions

1 A propellant expulsion system of pressurizing by means of a solid propellant cartridge, which is much lighter and more compact than a compressed gas system, has operated successfully to expel liquid oxygen and a 60% methyl alcohol/40% water mixture; the cartridge propellant weight is 4 lb 6 oz and the overall cartridge weight 9 lb for the R.T.V.1 motor giving a total impulse of about 19,000 lb sec.

2 Sealing of the liquid oxygen piston proved difficult, but was eventually achieved; a machined internal bore to the tank would have made the problem much easier. Sealing of the fuel piston presented little difficulty.

3 Owing to the leakage of liquid oxygen past the piston in the initial stages of the work it was necessary to use a propellant based on ammonium nitrate giving an excess of oxygen, in order to avoid secondary burning.

4 Successive batches of this propellant when mixed and tested by the manufacturers did not give the required performance in the rocket motor. Production charges must, therefore, be pressed from the same mixture of powder from which sample charges have been made and satisfactorily tested in R.T.V.1

5 To ensure repeatable performance all operations concerned with liquid oxygen must be carefully controlled within the time limits specified; this drawback is inherent in the use of liquid oxygen and will not be present with such oxidants as hydrogen peroxide or nitric acid.

REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc.</u>
1	Low Pressure Ballistics Section (White Lea)	Test experiments on the expulsion of liquid oxygen by a cordite charge A.R.E. Ballistics (L.P.B.) Note 134. August, 1946
2	H.G. Colliver, W.H. Bond, J.R. Smith and A.C. Merrington	Static and flight trials of the R.T.V.1 rocket motor - in draft.
3	H.G. Colliver, D.R.B. Ripp, A.C. Merrington	Development of a combustion chamber for the R.T.V.1 liquid oxygen-alcohol rocket motor. R.A.E. Report No. RPD.6. March, 1950.
4	H. Macpherson, J.R. Smith, K. Blythe, J.W. Orton	Assembly instructions for R.T.V.1. R.A.E. Tech.Note No. RPD.27. Feb. 1950.
5	H. Macpherson	Some manufacturing problems of R.T.V.1. R.A.E. Tech.Note No. RPD.31. June, 1950
6	J.W. Orton	Development of a cordite-operated fuel expulsion system for 7.2 in Ram Jet (Appendix) R.A.E. Tech.Note No. RPD.9. Dec. 1948.

Attached: Drgs. RP. 365 to 382

Advance Distribution:

M.O.S.

Chief Scientist	
P/DSR(A)	
ADSR(Records)	
D. Eng.RD	
Eng.RD6	
DCWRD	
ADGW(R & D)	
GW3, Cmdr. Ashworth	- 6
(incl. copies for Australian Representatives)	
P/DTD(A)	
ERDE Waltham Abbey	- 6

R.A.E.

Director	
DDRAE(W)	
G.Weapons	- 3
Naval A/c	
Chem. Dept	
Library	
Armament Dept	
TPA3/TIB	- 180

TABLE I

Summary of tests for producing final design of cartridge

Type	Fuel		Oxidant - Liquid Oxygen		Main Charge	Boost Charge	Breach Pressure		Remarks
	Flowrate lb/sec	Orifice dia.in	Flowrate lb/sec	Orifice dia.in			Max. lb/in ²	Av. lb/in ²	
25% Petrol 75% Kerosene	2.82	0.209	2.36	0.187	O.C. 7/0.5 3 lb 2 oz * S.I/A	Nil	330	260	Oxidant bursting disc 0.002" of aluminium ruptured at 75 lb/in ² after 5 sec. Fuel bursting disc 0.004" of aluminium ruptured at 140 lb/in ² after 6.5 sec.
Petrol	2.82	0.218	2.36	0.187	O.C. 7/0.5 3 lb 8 oz S.2/A	$\frac{1}{2}$ oz cylindrical pellets $\frac{3}{8}$ " dia. O.C. 7/0.0	320	225	Oxidant bursting disc 0.002" of aluminium ruptured at 90 lb/in ² after 1.5 sec. Fuel bursting disc 0.004" of aluminium ruptured at 320 lb/in ² after 12 sec.
Methanol 60/40	3.13	0.213	1.72	0.160	O.C. 7/0.5 3 lb 12 oz S.3/A	0.6 oz cylindrical pellets $\frac{3}{8}$ " dia. O.C. 7/0.0	425	325	Oxidant bursting disc 0.004" of aluminium ruptured at 320 lb/in ² after 4 sec. Fuel bursting disc 0.004" of aluminium ruptured at 320 lb/in ² after 4 sec.
"	"	"	"	"	O.C. 7/0.5 4 lb S.4/A	0.9 oz cylindrical pellets $\frac{3}{8}$ " dia. O.C. 7/0.0	415	365	Oxidant bursting disc 0.004" of aluminium ruptured at 250 lb/in ² after 1.75 sec. Fuel bursting disc 0.004" of aluminium ruptured at 270 lb/in ² after 2.75 sec.
"	"	"	"	"	O.C. 7/0.5 4 lb S.4/A	1.5 oz cylindrical pellets $\frac{3}{8}$ " dia. O.C. 7/0.0	390	340	Oxidant bursting disc 0.004" of aluminium ruptured at 270 lb/in ² after 1.25 sec. Fuel bursting disc 0.004" of aluminium ruptured at 275 lb/in ² after 1.5 sec.

* Denotes sample batch number

SECRET

Tech. Note No. RPD. 24

TABLE I (Cont'd)

Type	Fuel		Oxidant - Liquid Oxygen		Main Charge	Boost Charge	Breach Pressure		Remarks
	Flowrate lb/sec	Orifice dia.in	Flowrate lb/sec	Orifice dia.in			Max. lb/in ²	Av. lb/in ²	
Methanol 60/40	3.13	0.213	1.72	0.160	O.C. 7/0.5 4 lb *S.4/A	1.5 oz cylindrical pellets 3/8" dia. O.C. 7/0.0. 1 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	430	377	Oxidant bursting disc 0.006" of aluminum ruptured at 325 lb/in ² after 2.75 sec. Fuel bursting disc 0.006" of aluminum ruptured at 325 lb/in ² after 2.75 sec.
"	"	"	"	"	O.C. 7/0.5 4 lb S.5/A	2.5 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	520	375	Oxidant bursting disc 0.006" of aluminum failed to rupture. Fuel bursting disc 0.006" of aluminum ruptured at 290 lb/in ² after 1.5 sec. Safety disc ruptured at 520 lb/in ² after 10 sec.
"	"	"	"	"	O.C. 7/0.5 4 lb S.5/A	2.5 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	395	337	Oxidant bursting disc 0.002" of aluminum ruptured at 75 lb/in ² after 1.5 sec. Fuel bursting disc 0.006" of aluminum ruptured at 300 lb/in ² after 3 sec.
"	"	"	"	"	O.C. 7/0.5 4 lb S.6/A	2.5 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	375	345	Oxidant bursting disc 0.002" of aluminum ruptured at 95 lb/in ² after 1 sec. Fuel bursting disc 0.006" of aluminum ruptured at 300 lb/in ² after 1.75 sec.
"	"	"	"	"	O.C. 7/0.7 4 lb 3 S.7/A	2.5 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	375	330	Oxidant bursting disc 0.003" of aluminum ruptured at 230 lb/in ² after 1.25 sec. Fuel bursting disc 0.006" of aluminum ruptured at 340 lb/in ² after 1.5 sec.

* Denotes sample batch number

SECRET

TABLE I (Cont'd)

Type	Fuel		Oxidant - Liquid Oxygen		Main Charge	Boost Charge	Breach Pressure		Remarks
	Flowrate lb/sec	Orifice dia.in	Flowrate lb/sec	Orifice dia.in			Max. lb/in ²	Av. lb/in ²	
Methanol 60/40	3.13	0.213	1.72	0.160	O.C. 7/0.7 4 lb 3 oz *S.8/A	3 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	500	500	Oxidant bursting disc 0.003" of aluminum ruptured at 230 lb/in ² after 1 sec. Fuel bursting disc 0.006" of aluminum ruptured at 300 lb/in ² after 1 sec.
"	"	"	"	"	O.C. 7/0.7 4 lb 3 oz S.9/A	2.5 oz cylindrical pellets 3/16" dia. O.C. 7/2.5	465	435	Oxidant bursting disc 0.002" of aluminum ruptured at 100 lb/in ² after 0.75 sec. Fuel bursting disc 0.006" of aluminum ruptured at 310 lb/in ² after 1 sec.

* Denotes sample batch number

SECRET

SECRET

TABLE II

Comparison between predicted and actual
performance of cartridge

Cartridge		Manufacturer's Predicted Pressure	Average Pressure obtained in RTV1
Batch No.	Weight		
O.C. 7/0.5 S.1/A	3 lb 2 oz	300 lb/in ²	260 lb/in ²
O.C. 7/0.5 S.2/A	3 lb 8 oz	350 "	225 "
O.C. 7/0.5 S.3/A	3 lb 12 oz	400 "	325 "
O.C. 7/0.5 S.4/A	4 lb	450 "	365 "
O.C. 7/0.5 S.5/A	4 lb	450 "	337 "
O.C. 7/0.5 S.6/A	4 lb	400 "	345 "
O.C. 7/0.7 S.7/A	4 lb 3 oz	400 "	330 "
O.C. 7/0.7 S.8/A	4 lb 3 oz	450 "	500 "
O.C. 7/0.7 S.9/A	4 lb 3 oz	450 "	435 "

APPENDIX IFitting the oxidant piston

This operation must be carried out with considerable care if success in operation is to be assured. The inside diameter of the particular oxidant tank to be fitted with a piston is measured at the stations shown in Fig. 18. A typical list of measurements is shown in the table below:

Station	A	B	C	D
Vert. Dia.	8.026	8.026	8.014	8.013
Horiz. Dia.	8.028	8.017	8.013	8.007
Mean Dia.	8.027	8.022	8.014	8.010
Overall Mean Dia		8.018		

The measurements at station A are only taken to check that the forged end ring has been scraped (after welding) so that its bore blends smoothly into the bore of the tube. The overall mean diameter is obtained from all the measurements taken at stations B, C and D. A piston is selected with a skirt diameter at least 0.005 in less than the smallest mean diameter of the tank at any station. In the example cited above the maximum diameter of piston to be used would be 8.005 in i.e. 0.005 in less than the mean diameter at station D. If the manufacturing tolerances on the piston have been kept, this condition should automatically be satisfied. The edge of the piston skirt is belled out by means of the tool shown in Fig. 19 until it is 0.005 in greater in diameter than the mean diameter of the tank. In the example given this dimension would be 8.023 in.

Two flat, degreased, water-dressed leather washers are assembled on the piston with the smooth sides of the washers facing outwards. A clamping ring, secured by six equally-spaced nuts tightened up on lead washers, holds the leather washers in place on the piston. The piston is set up in a lathe so that the skirt immediately adjacent to the washers is running true, then the leather washers are turned down by means of a very sharp tool, until their outside diameter is 0.010 ± 0.001 in greater than the mean diameter of the particular oxidant tank which they are intended to fit. Using the example given previously this dimension would be 8.028 ± 0.001 in. The six nuts securing the clamping ring to the piston are now removed together with the flat washers and lead washers. The clamping ring is then eased forward until the gap between the ring and the piston is approximately $\frac{1}{8}$ in.

The piston is offered to the tank, and pressed into position by hand pressure only, care being taken that the slots in the piston skirt register with the gas pipe apertures in the tank. If the leather washers have been machined to the correct dimensions the piston can be pressed home by hand pressure. The domed closing plate fitted with its sealing washer is used to bring the piston to its final position in the tank. The nuts securing the clamping ring are then tightened in diametrically opposite pairs until the lead washers commence to extrude slightly under the pressure. Should it be necessary to remove a piston for any reason an extractor similar to that shown in Fig. 20 must be used.

APPENDIX IILiquid Oxygen Vent Valve

Owing to the small tolerances permitted on the vent valve components it is essential that the following physical checks are carried out on each vent valve in the particular oxidant tank to which the valve is fitted.

1 Assemble the valve in the boss on the tank with the shear wire fitted, but without the spring. Screw down the valve cap and ensure that the shear wire remains intact. Dismantle the valve.

2 Assemble the valve in the boss without the shear wire or spring and depress the plunger from inside the oxidant tank. The end of the plunger should fall at least 0.010 in below the inside surface of the tank. Dismantle the valve.

3 Assemble the spring on the valve plunger and check that when the spring is coil-bound the top coil comes at least 0.020 in below the top of the plunger.

The valve is then assembled in a special test housing complete with shear pin, plunger and spring. The plunger is depressed, thereby shearing the pin, and the spring holds the valve on its seat. The test housing is screwed into a small pressure vessel of 48 cub. in capacity and the vessel is pressurized to 400 lb per sq in by dry nitrogen and then sealed. The valve is permitted to leak sufficiently to allow the pressure to drop 25 lb per sq in over 20 seconds. After testing, a new shear pin is fitted and the valve assembly is packed in a dust-proof container until required for use.

APPENDIX IIIAssembly of the oxidant tank lagging

Each gas delivery pipe is prevented from touching the tank by inserting $\frac{1}{2}$ in squares of asbestos sheet $\frac{1}{8}$ in thick between the pipe and the tank at the beginning and end of each expansion bend. The sleeve is then pulled over the tank and attached to the flange at the forward end of the tank by Bostik cement. A circle is cut out of the sleeve to correspond with the vent valve, and the edge of the circle is stuck by Bostik cement to a small wooden former surrounding the vent valve boss. As the efficiency of the lagging affects the evaporation rate of liquid oxygen, which in turn affects the performance of the cartridge, the lagging process is very carefully controlled. Exactly 4 lb of dry magnesium carbonate powder is weighed, and this quantity is distributed evenly between the sleeve and the tank before the end of the sleeve is attached to the flange at the rear end of the tank. The concave closing plate at the front end of the tank is filled with 8 oz of magnesium carbonate. The powder is consolidated by shaking, then sealed by means of a cardboard disc which is sealed around its edge by Bostik cement. A special plate was made to retain the powder at the breech end of the oxidant tank. The seal around the edges is made by placing a fillet of Bostik cement and asbestos fibre round the edge before securing the plate in position by grub screws. The space between the end of the tank and the plate is filled with $2\frac{3}{4}$ oz of magnesium carbonate through the central aperture which is sealed by a cover plate.

The oxidant delivery pipe to the combustion chamber is lagged with two layers of $\frac{3}{32}$ in thick asbestos tape which is covered with one layer of P.V.C. adhesive tape.

SECRET

TECH. NOTE: R.P.D. 24

FIG.1.

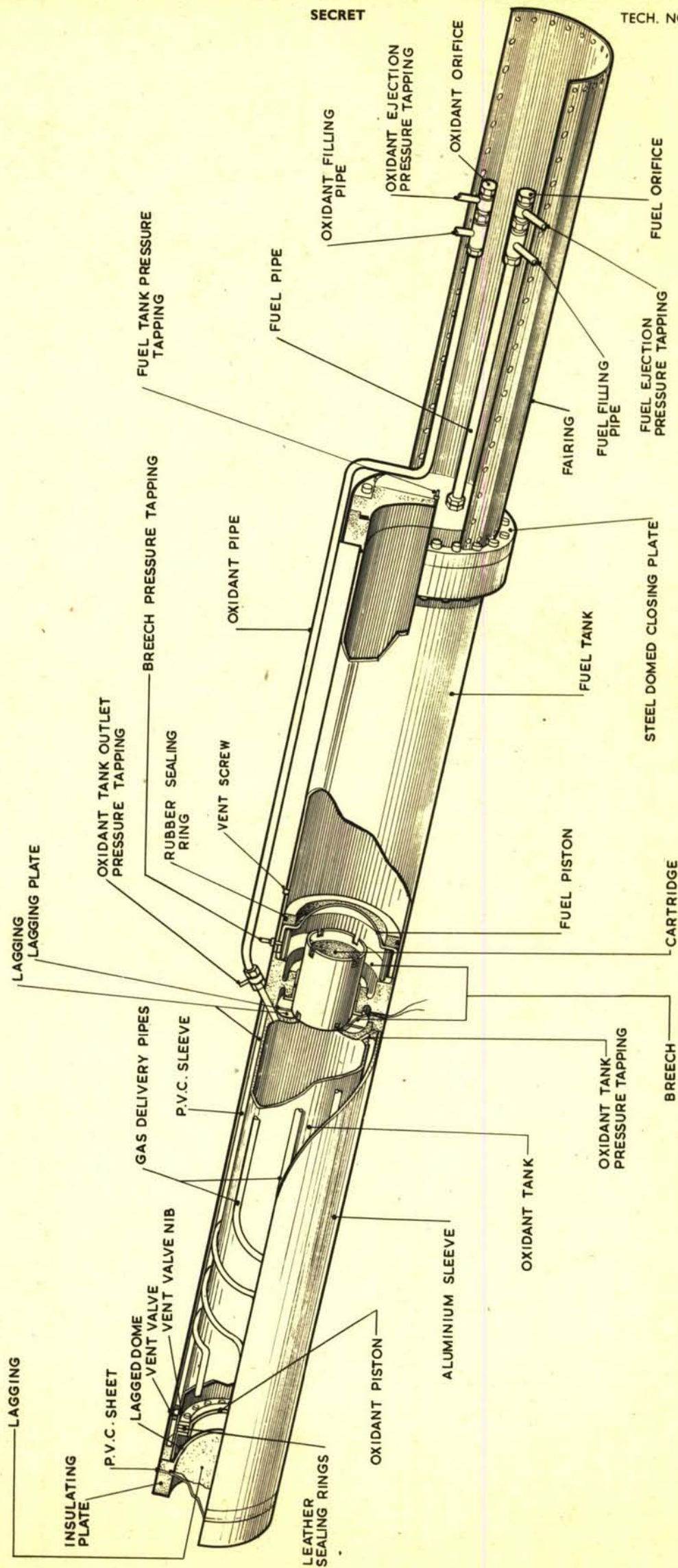


FIG.1. LAYOUT OF PROPELLANT FEED SYSTEM

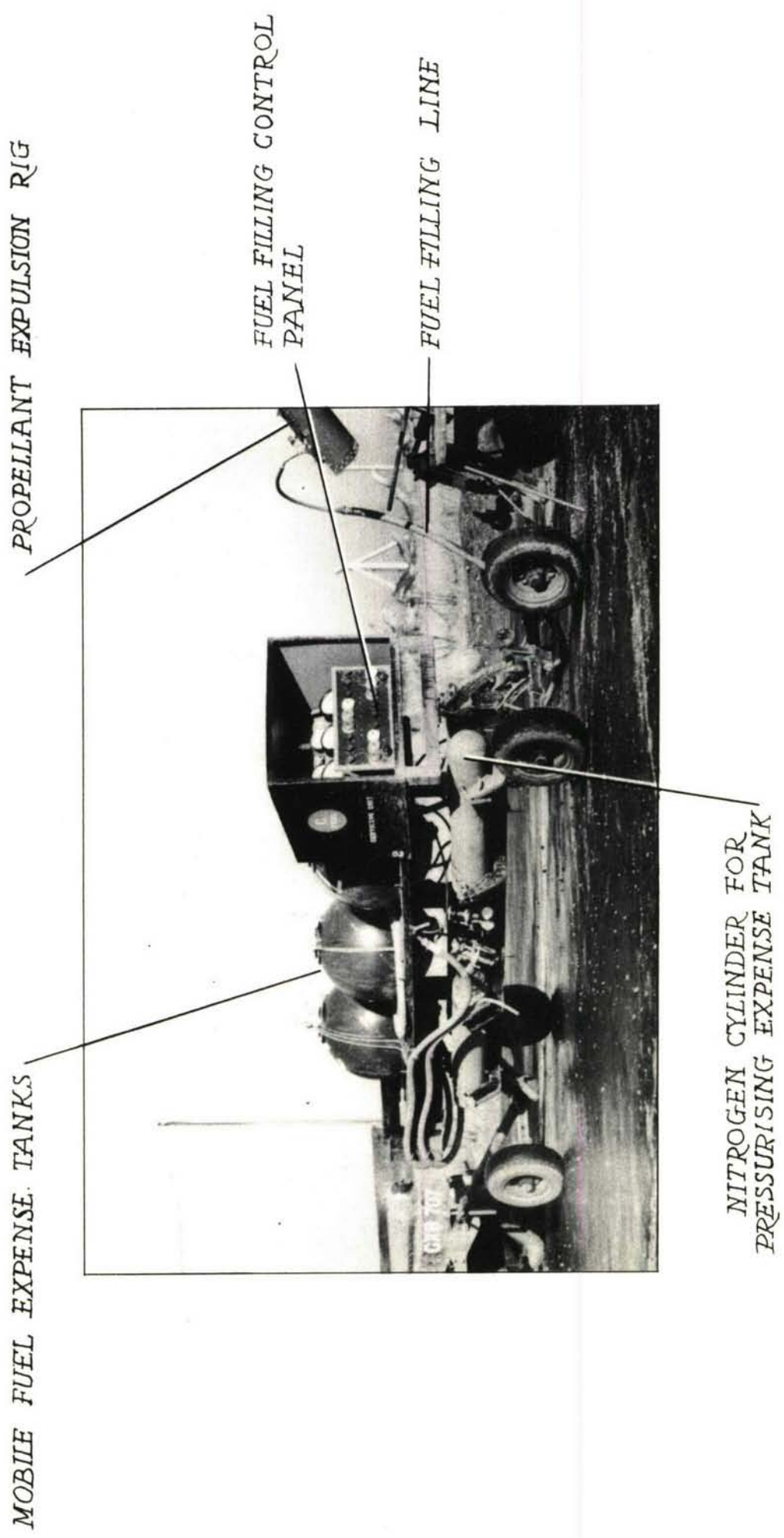


FIG.2. FUEL TANK FILLING OPERATION

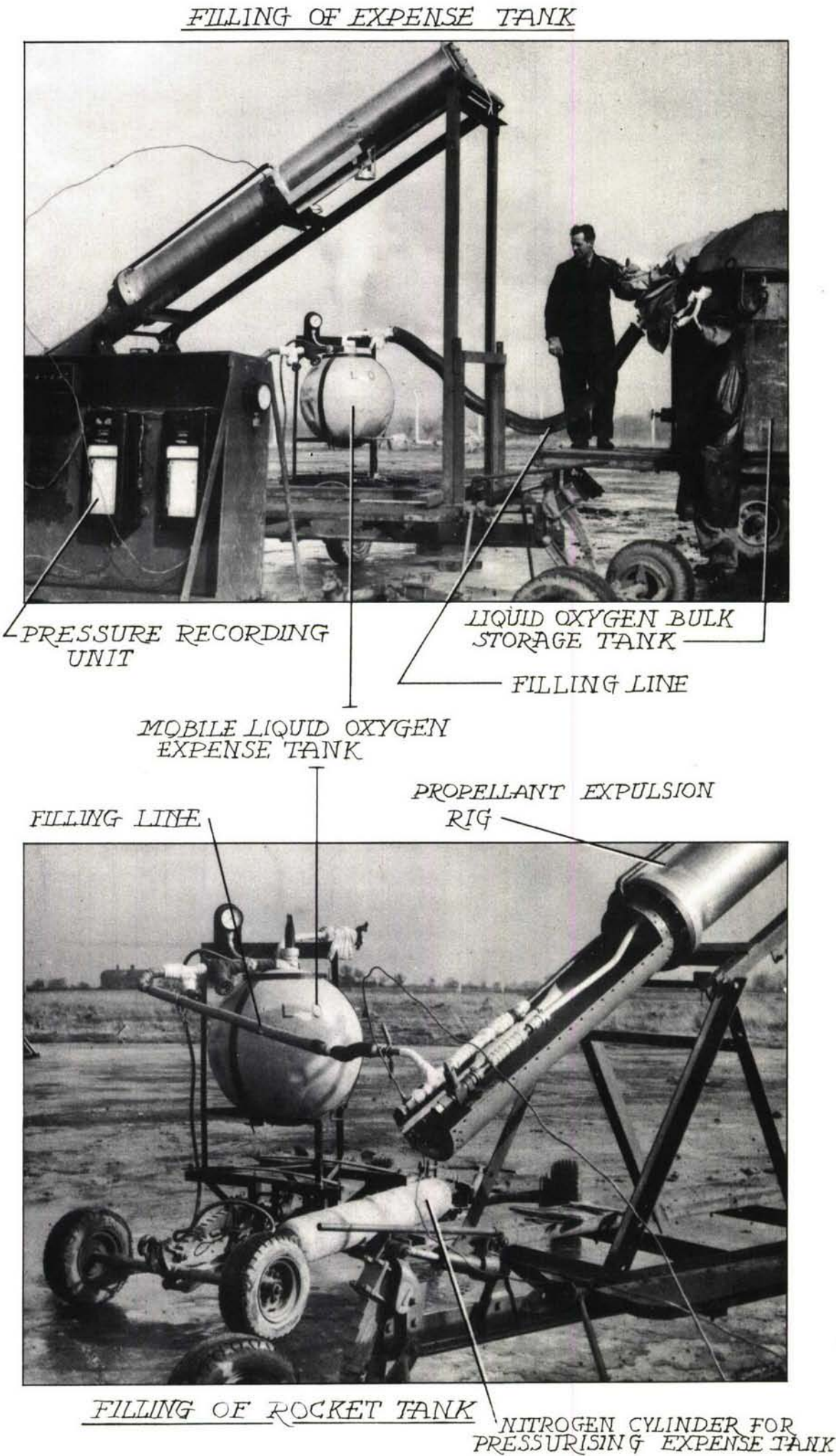


FIG.3. OXIDANT TANK FILLING OPERATION

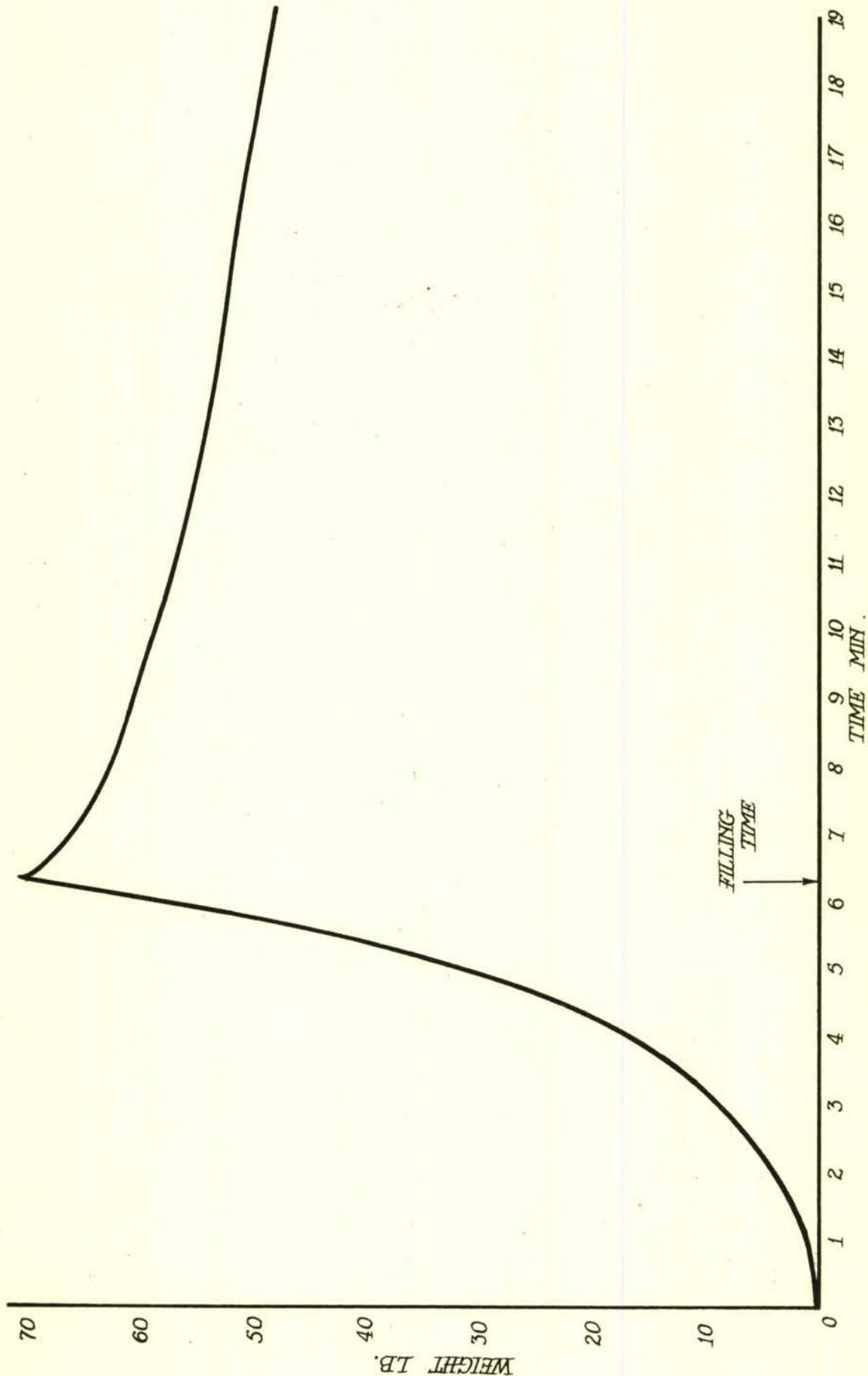


FIG.4. VARIATION IN WEIGHT OF LIQUID OXYGEN IN OXIDANT TANK DURING AND AFTER FILLING

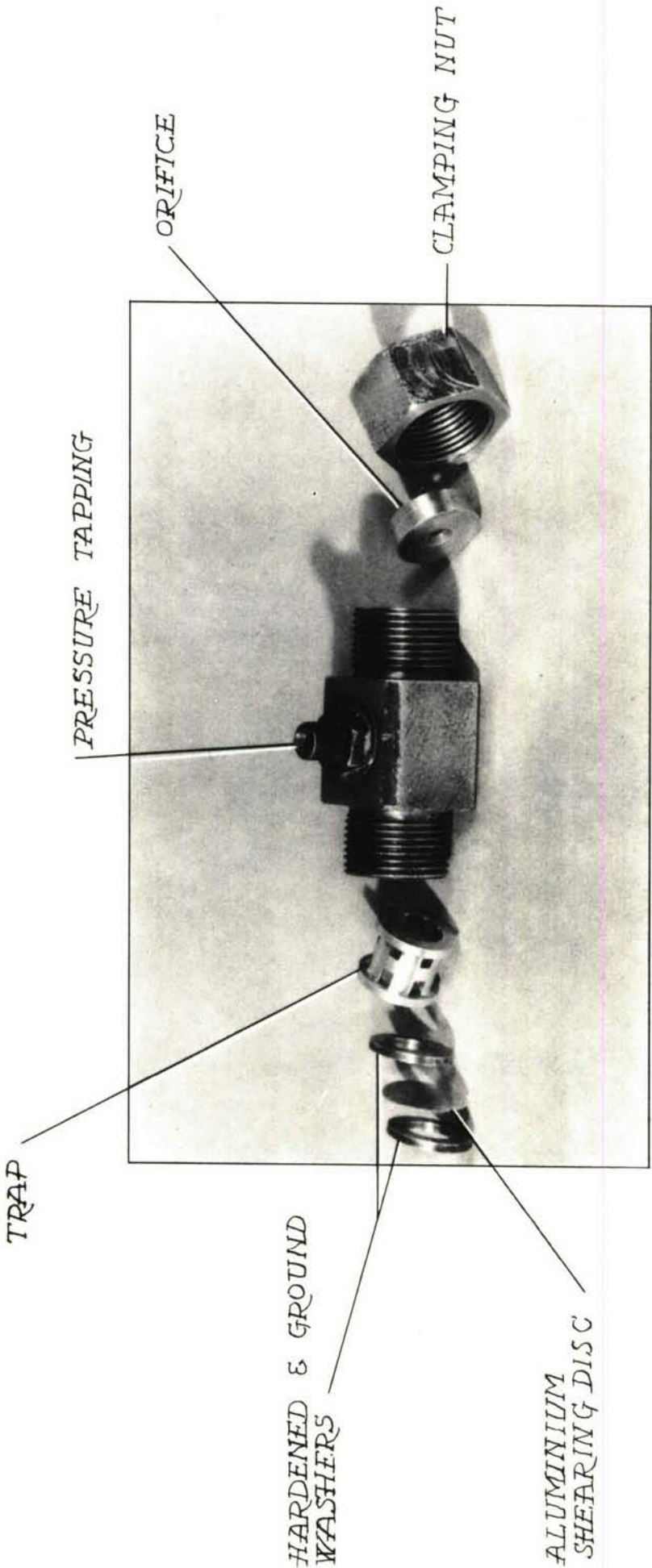


FIG.5. ORIFACE FITTING

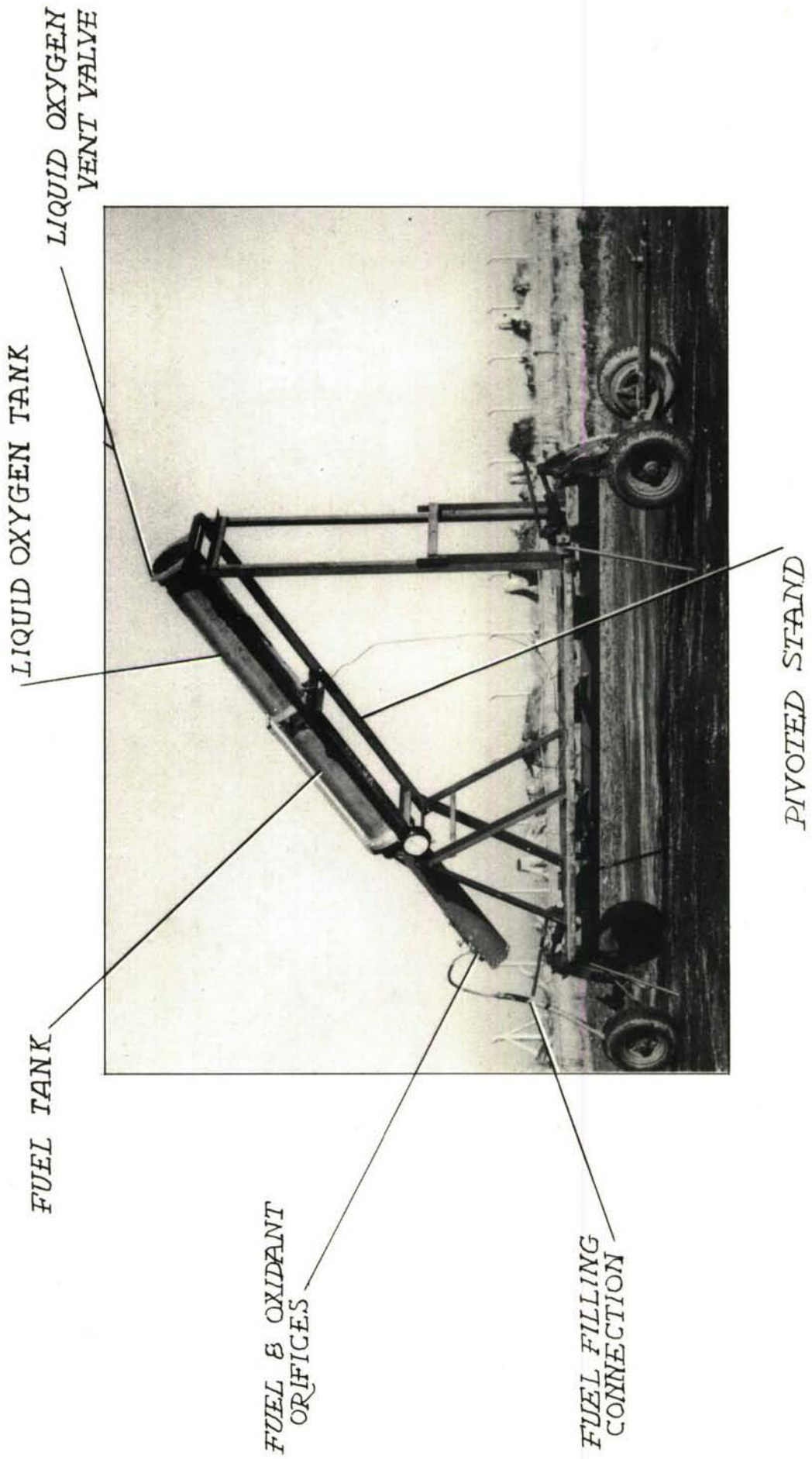


FIG.6. MOBILE TEST STAND

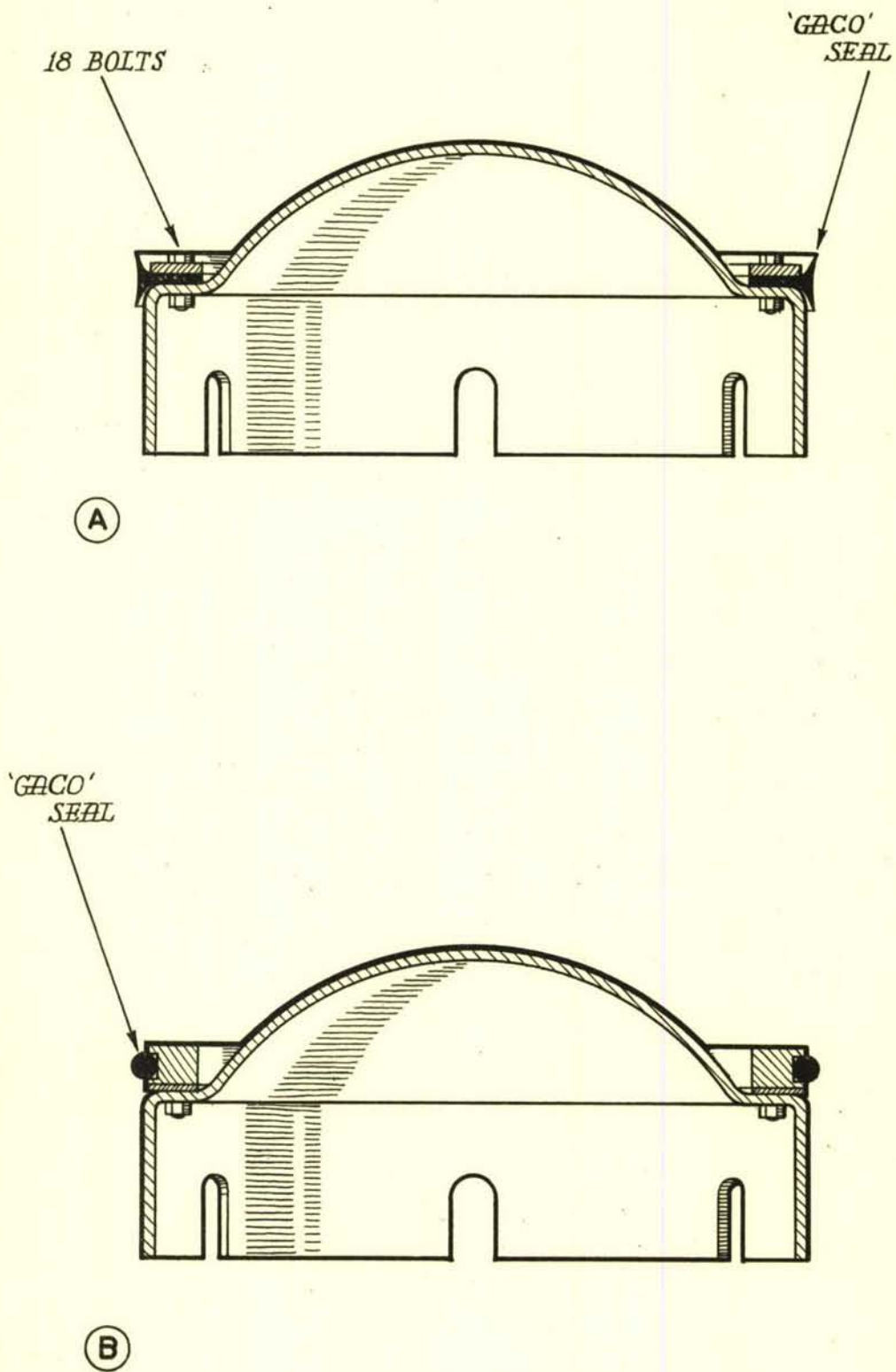
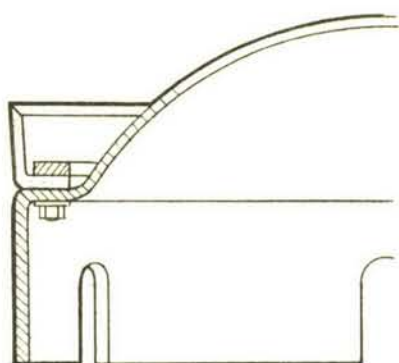
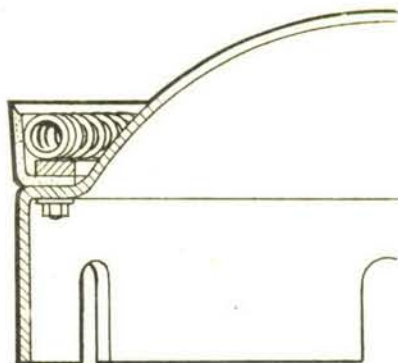


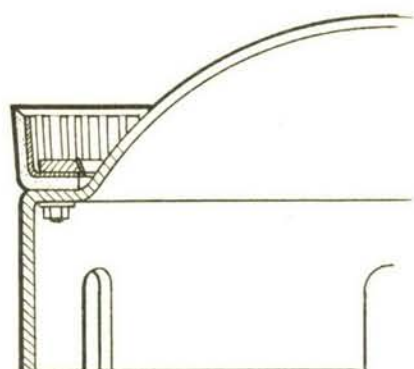
FIG.7. ORIGINAL DESIGN OF OXIDANT PISTON



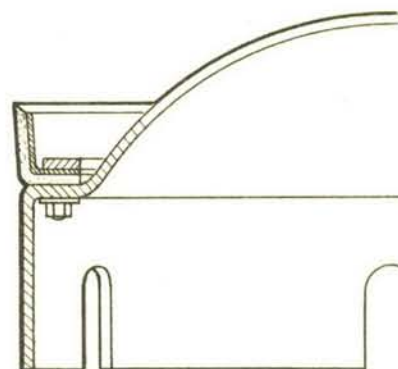
(a) CUP LEATHER WASHER



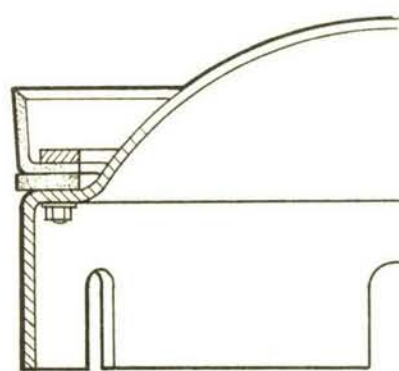
(b) CUP LEATHER WASHER
OBTURATED BY SPIRAL SPRING



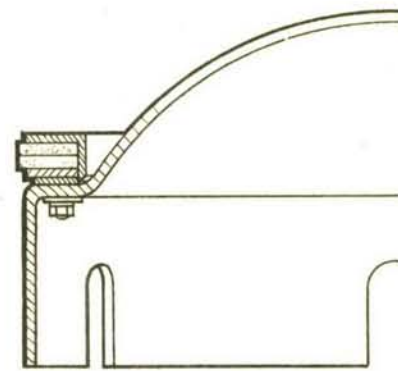
(c) CUP LEATHER WASHER
OBTURATED BY LEAF SPRINGS



(d) CUP LEATHER WASHERS
OBTURATED BY DISHED PLATE



(e) CUP LEATHER WASHER
& FLAT LEATHER WASHER



(f) FLAT LEATHER WASHER WITH
FLANGED CLAMPING RING

FIG.8. EXPERIMENTAL OXIDANT PISTON SEALS

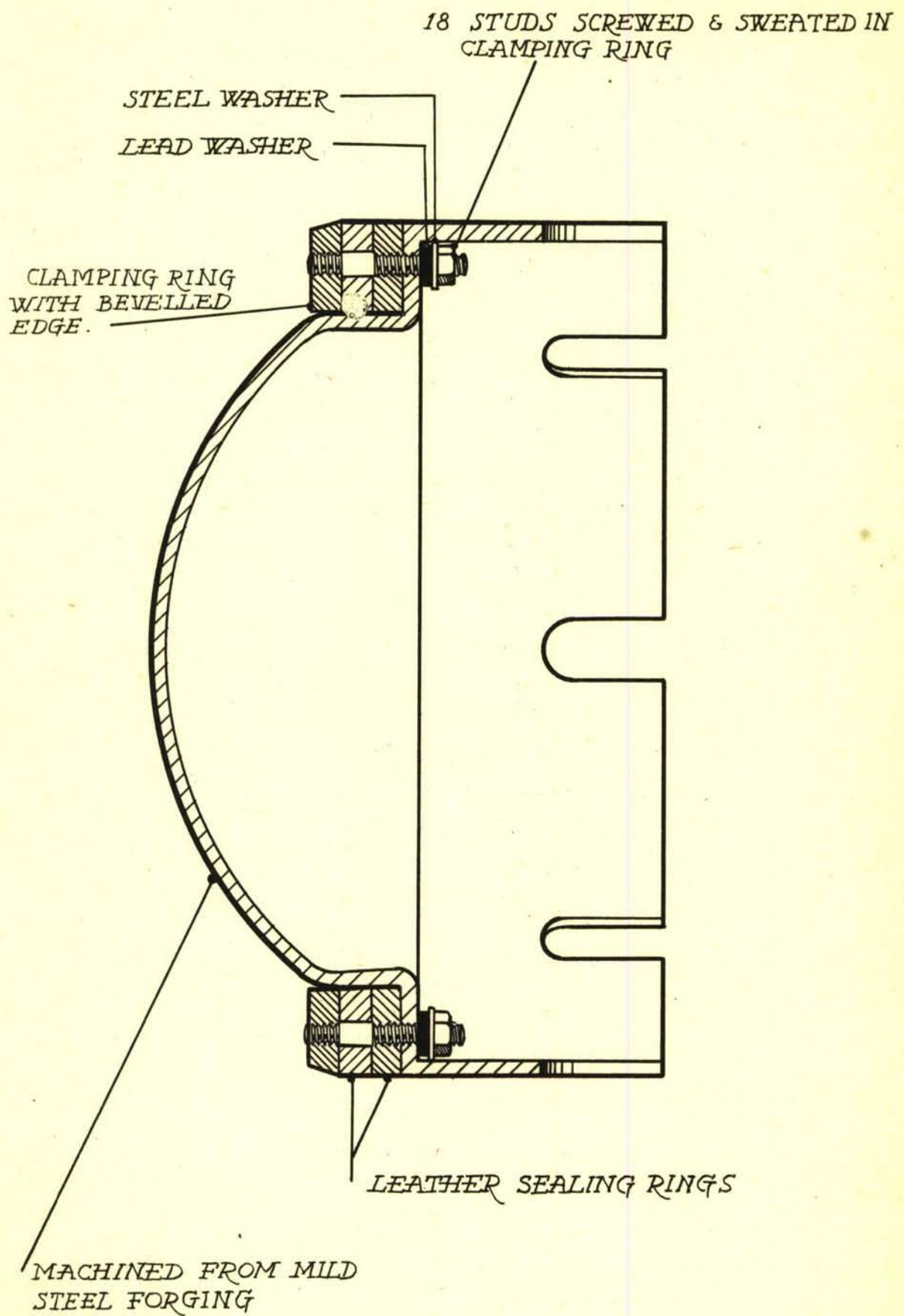


FIG.9. FINAL DESIGN OF OXIDANT PISTON

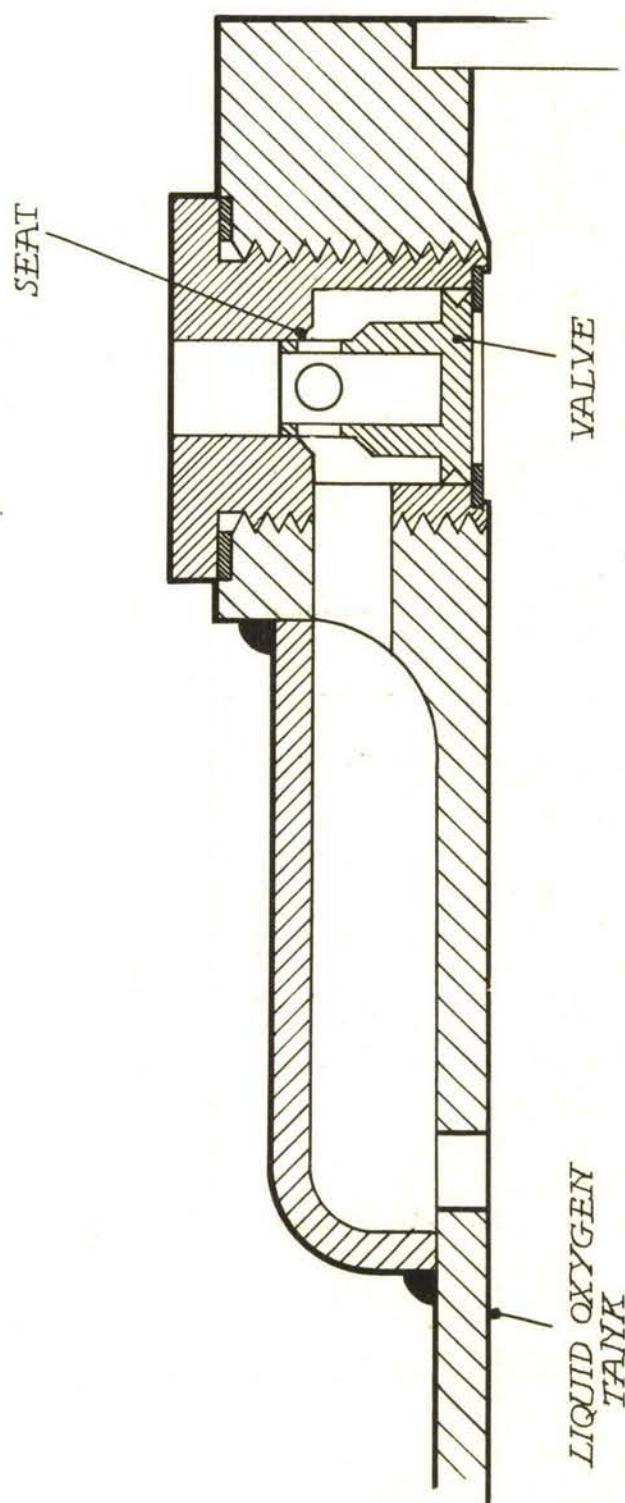


FIG.10. ORIGINAL OXIDANT TANK VENT VALVE

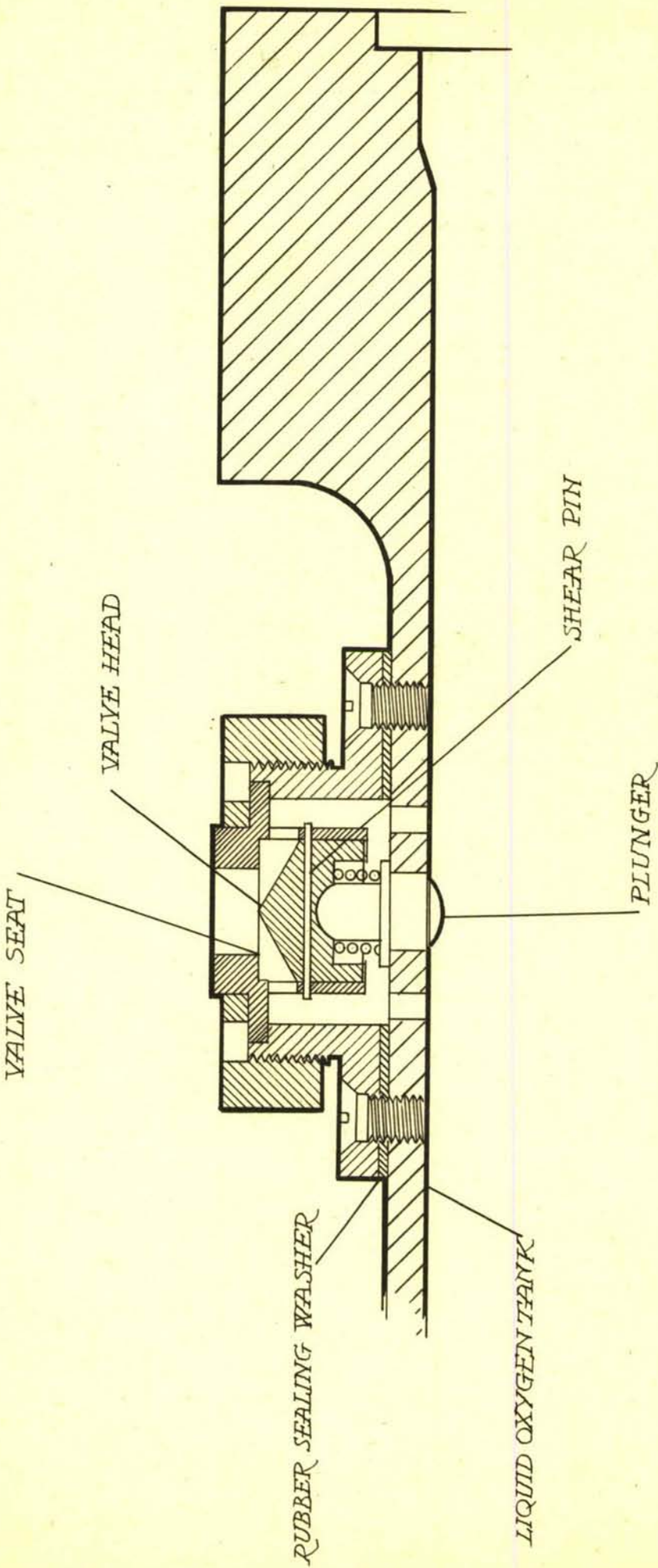


FIG.11. FINAL DESIGN OF OXIDANT TANK VENT VALVE

SECRET

FIG.12

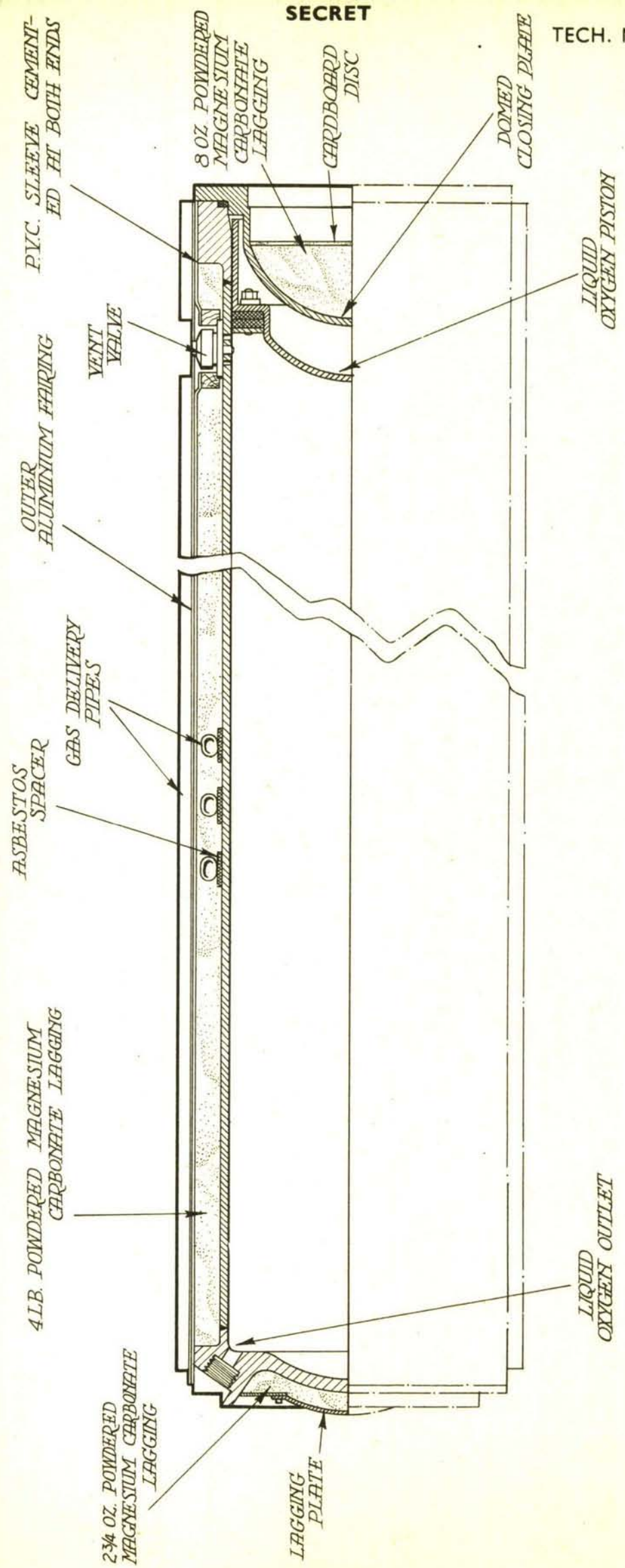


FIG.12. OXYGEN TANK LAGGING

SECRET

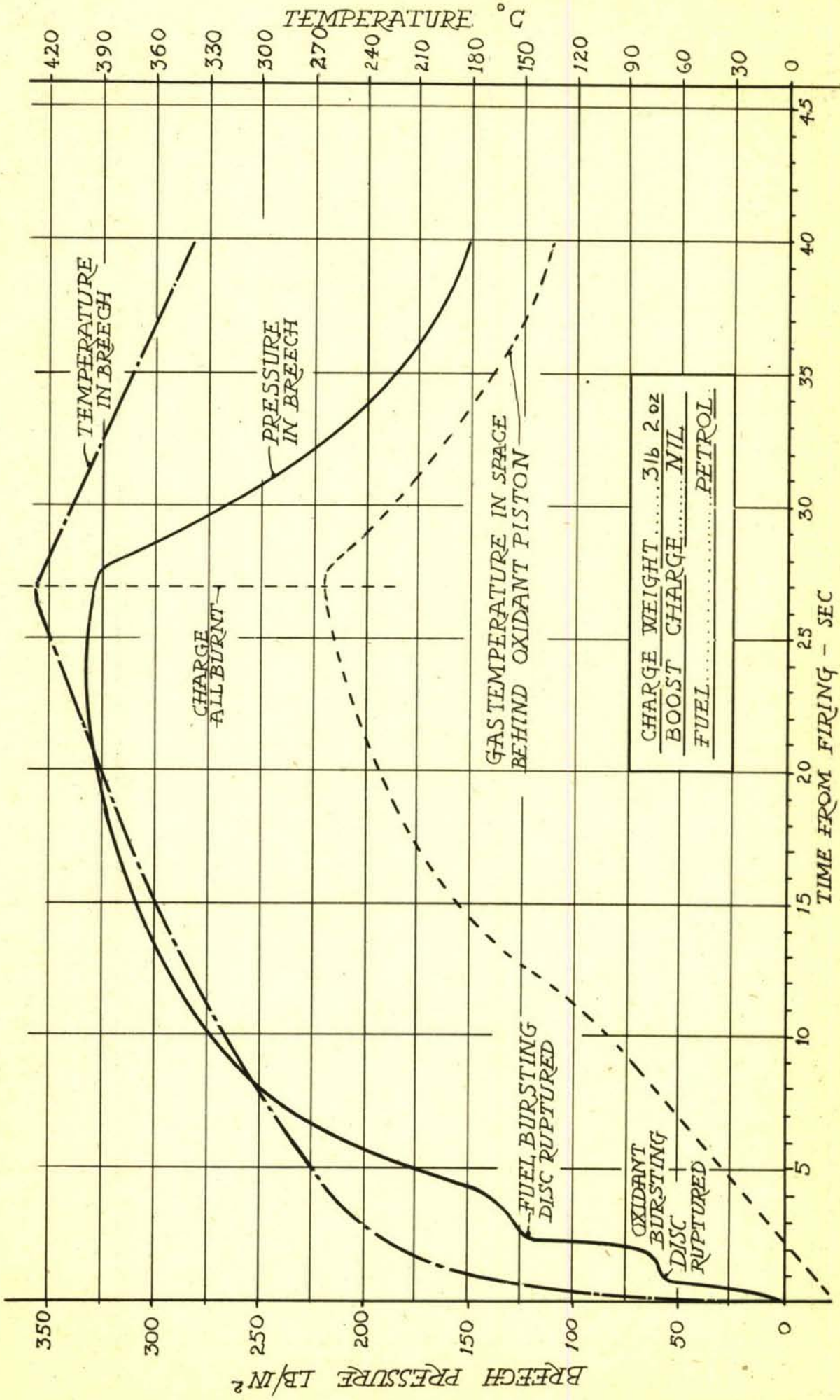


FIG.13. TYPICAL BREECH PRESSURE AND TEMPERATURE RECORD DURING FUNCTIONING TESTS

FIG.14

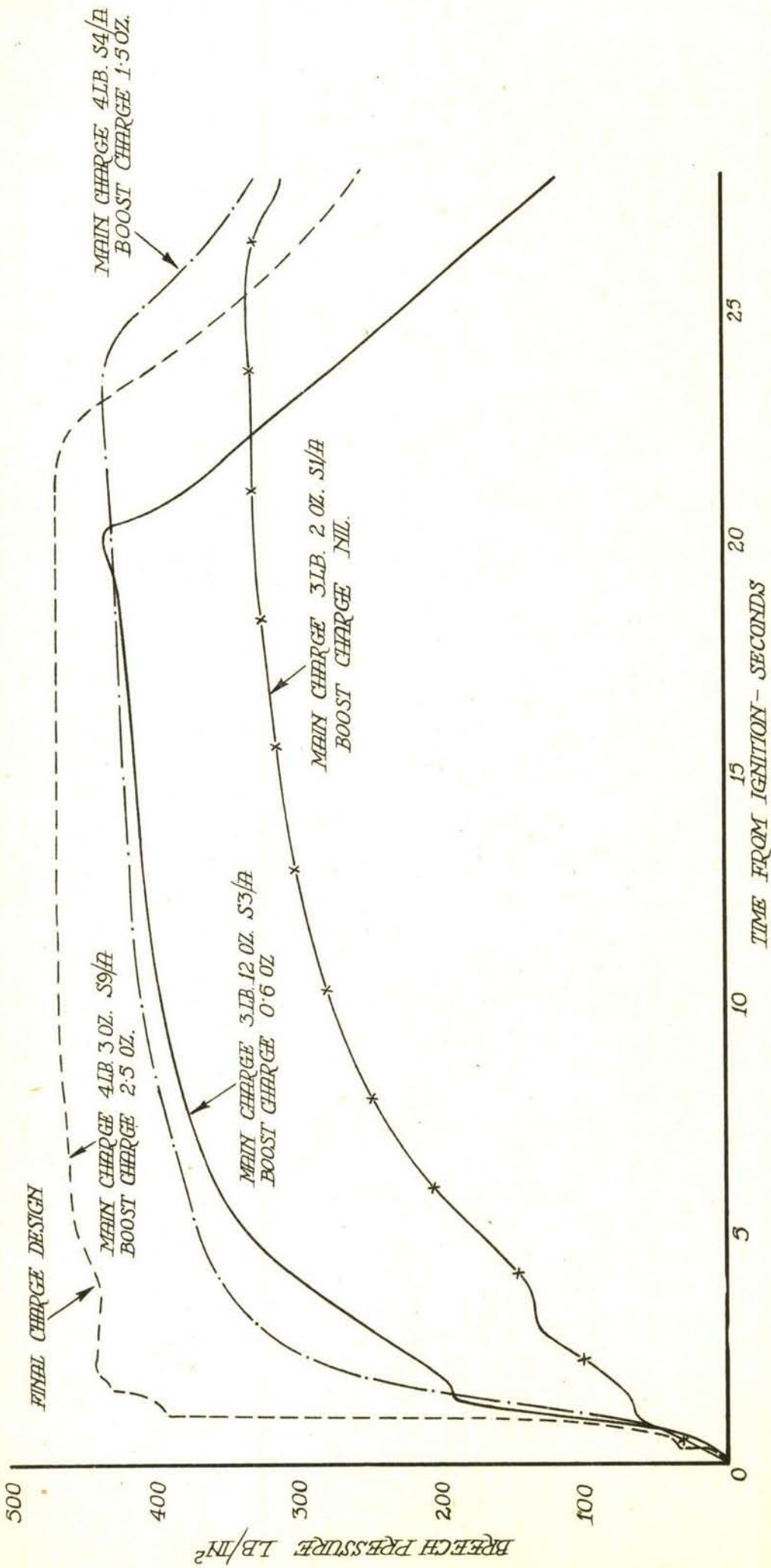


FIG.14. TYPICAL GAS PRESSURE RECORDS FROM BREECH DURING CHARGE DEVELOPMENT TESTS

OVERALL CARTRIDGE WEIGHT 9 lb.

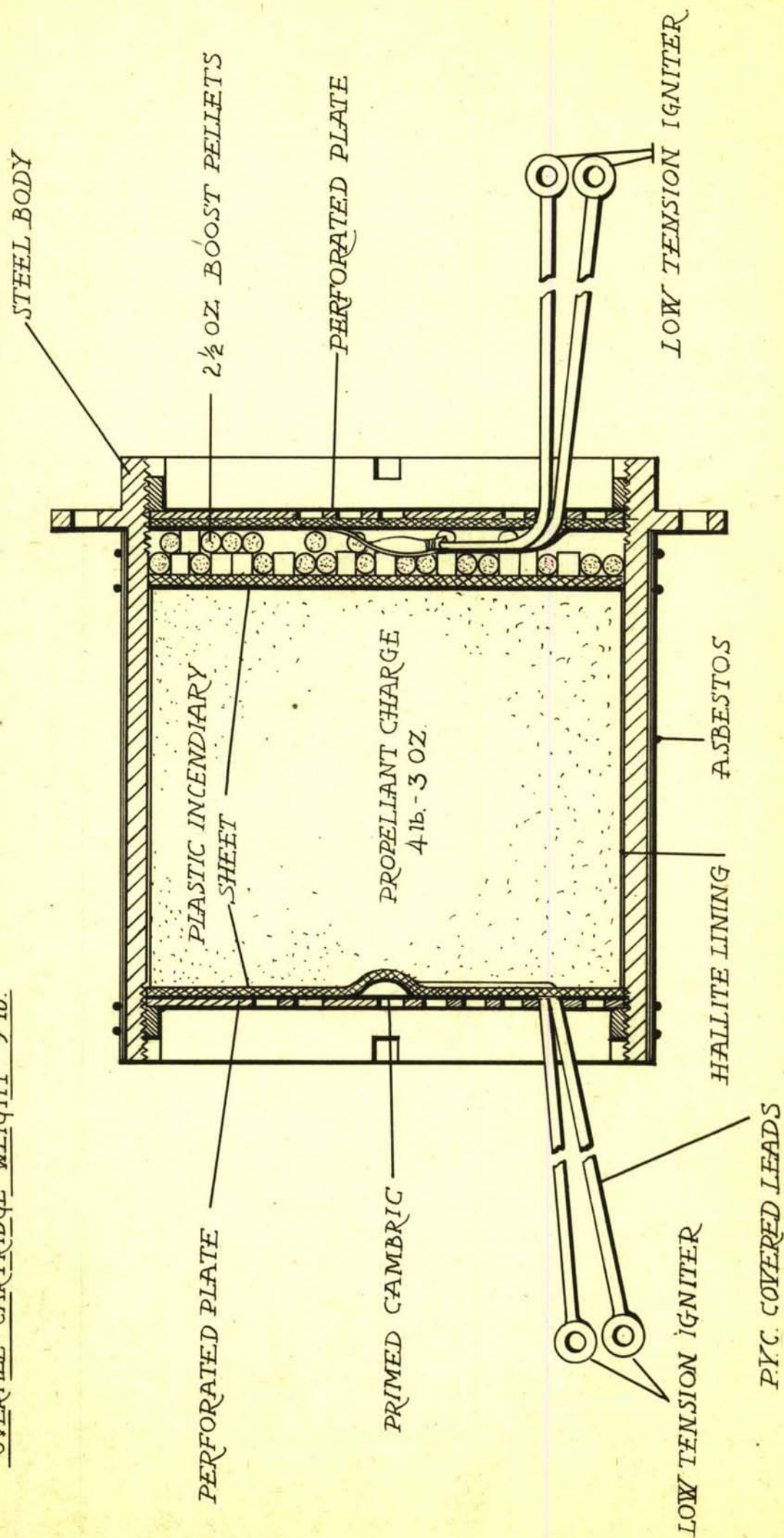


FIG.15. ASSEMBLY OF CARTRIDGE

FIG.16

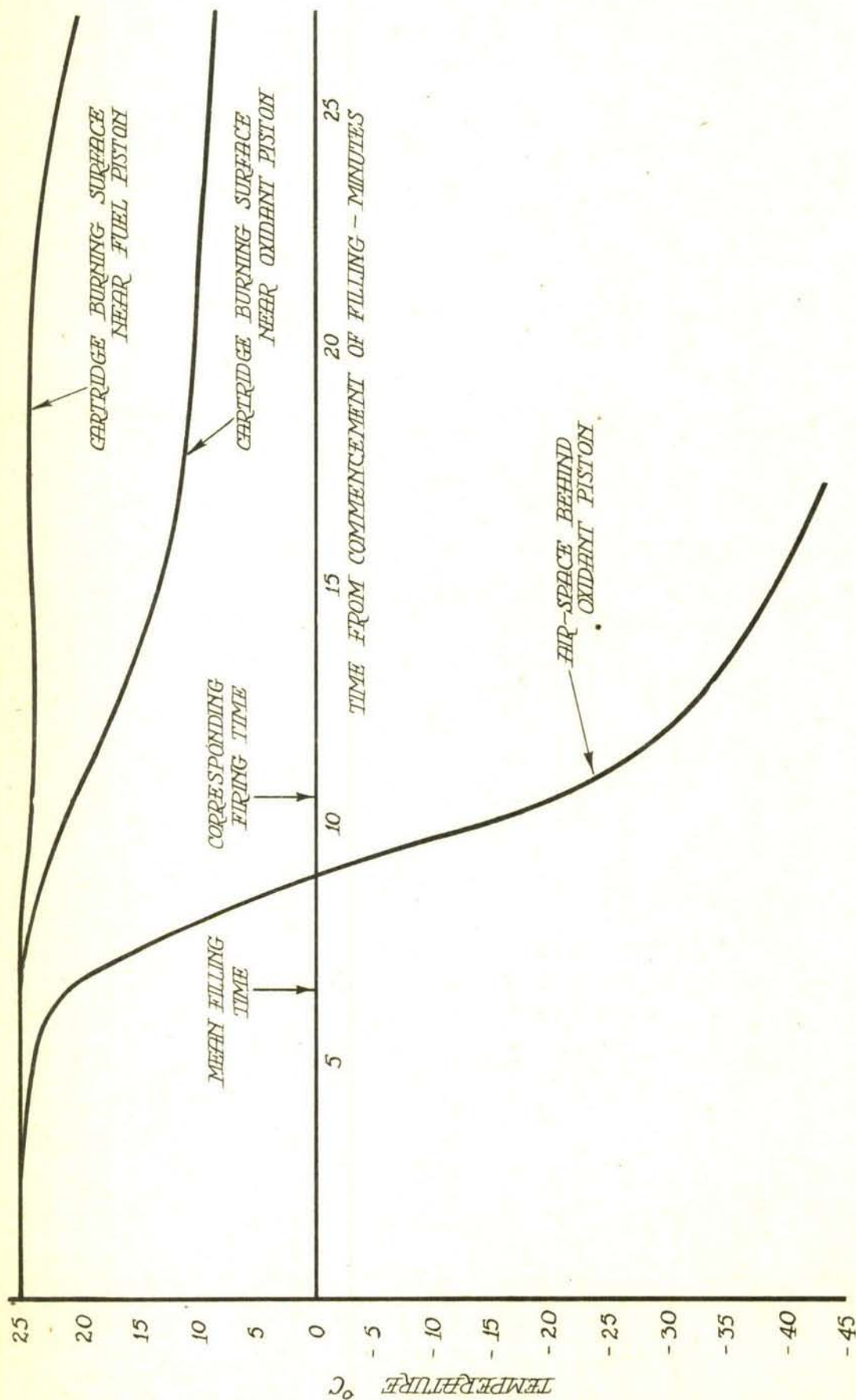


FIG.16. TEMPERATURE VARIATION AT BURNING SURFACES OF CARTRIDGE AND IN AIR-SPACE BEHIND OXIDANT PISTON DURING AND AFTER OXIDANT FILLING

FIG.17

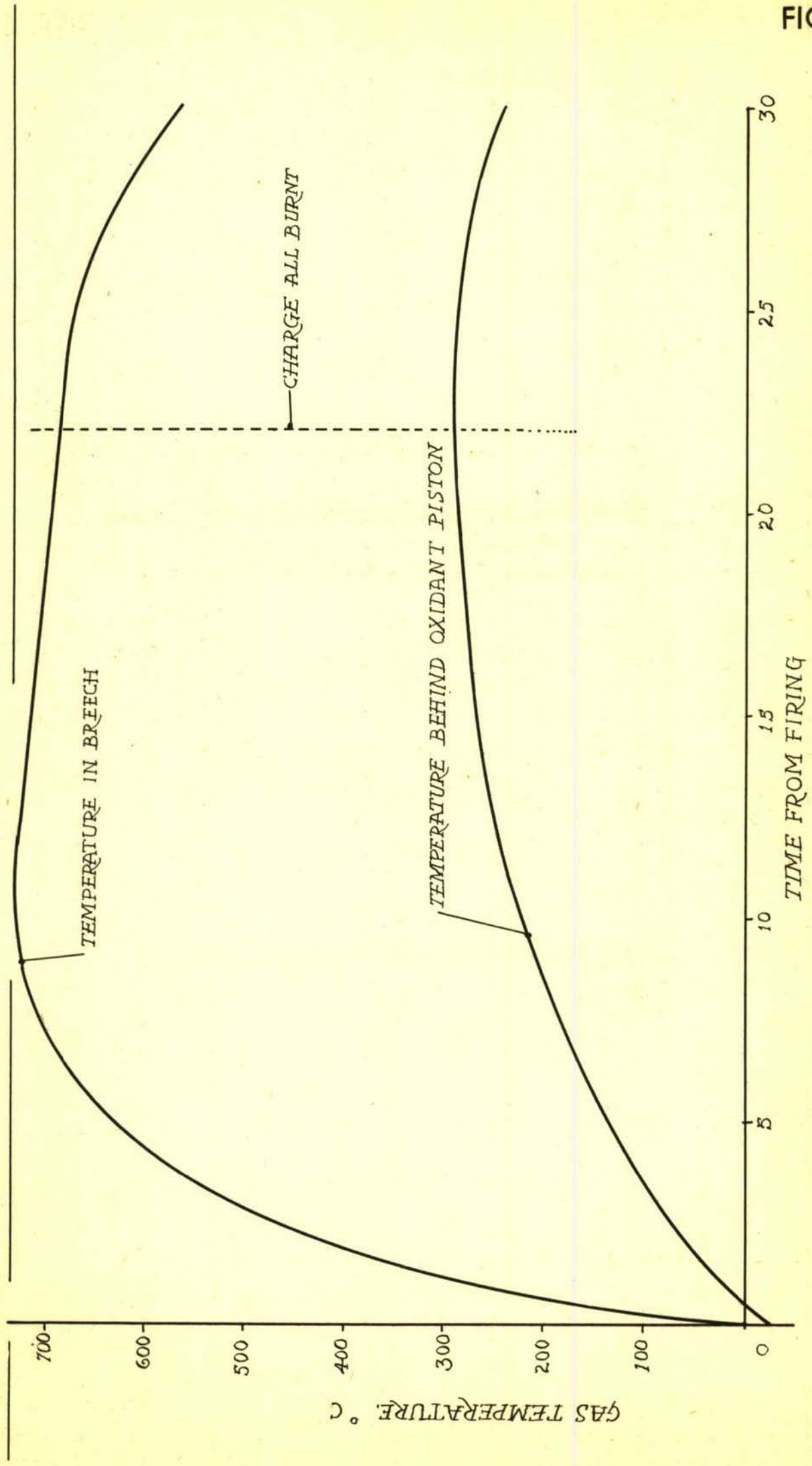


FIG.17. TYPICAL GAS TEMPERATURE RECORDS FROM BREECH AND BEHIND OXIDANT PISTON USING FINAL CHARGE

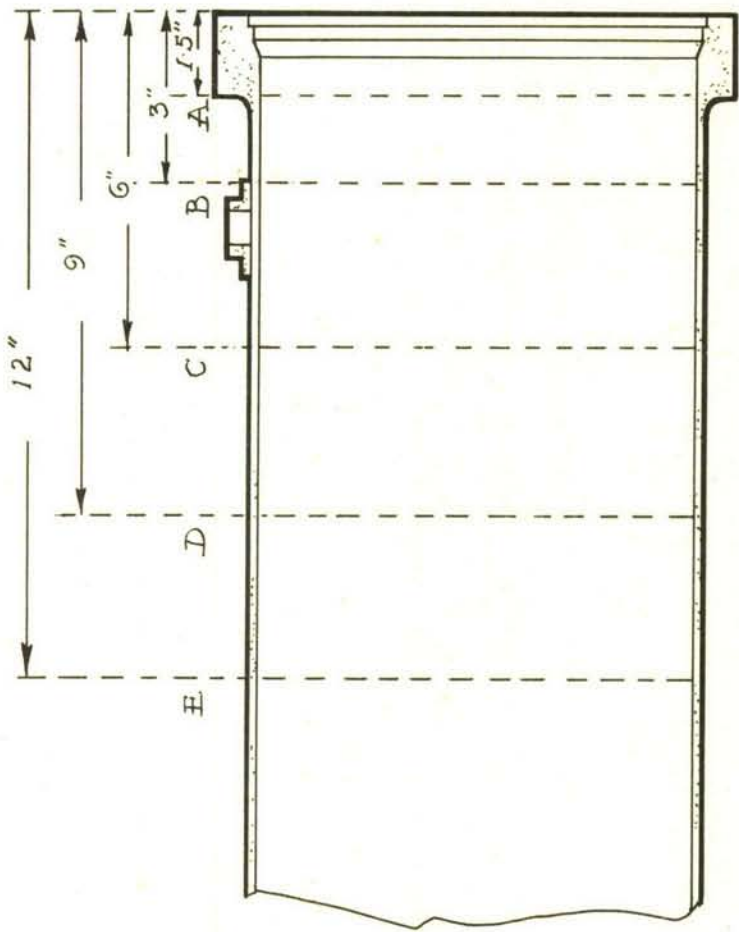


FIG.18. MEASUREMENT OF OXIDANT TANK BORE

~~SECRET~~
UNCLASSIFIED

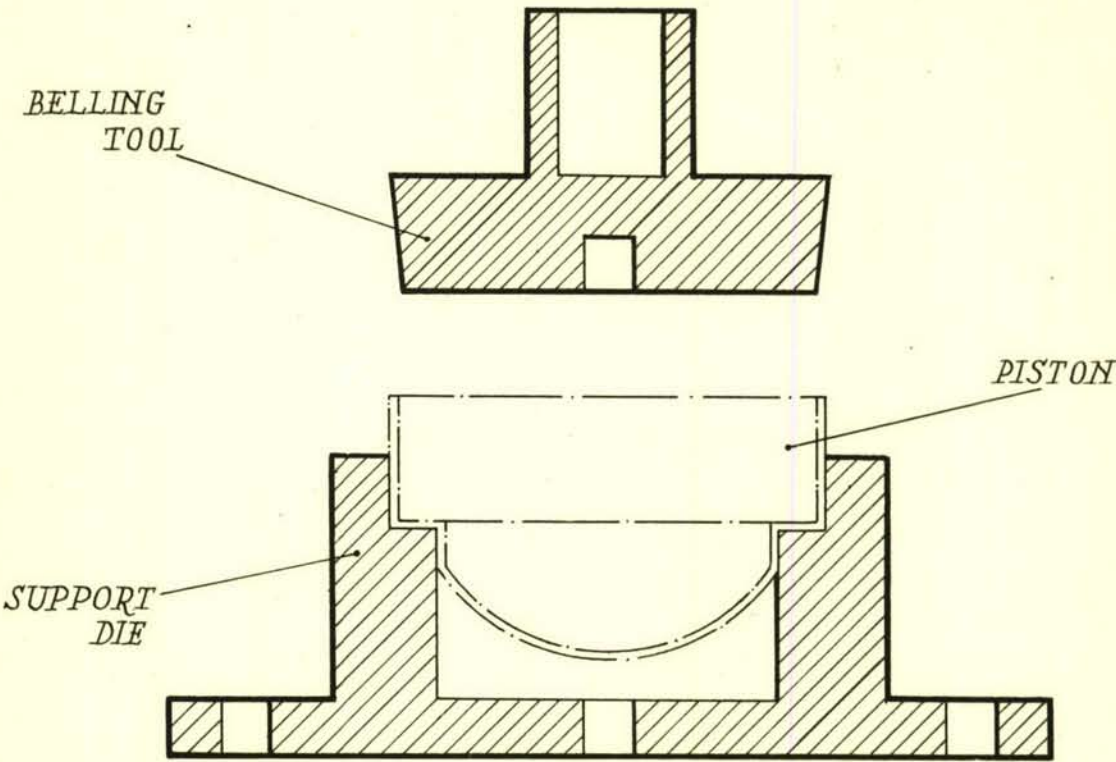


FIG.19. OXIDANT PISTON BELLING TOOL

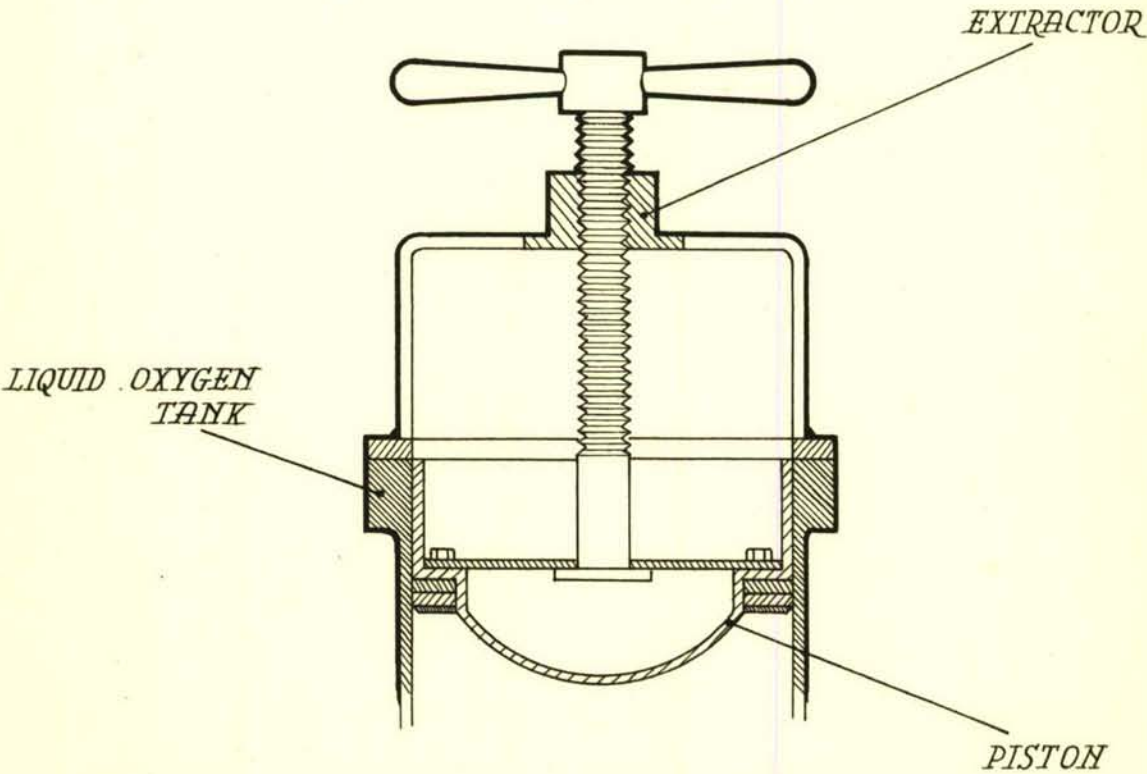


FIG.20. OXIDANT PISTON EXTRACTOR

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~

~~SECRET~~

UNCLASSIFIED